PAPER

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Viability analysis of mini-grid based electrification in Ghana

EXECUTIVE SUMMARY

Background

Ghana is a shining example to many sub-Saharan African countries with regards to grid extension, managing to extend electricity access to about 84% of the country. However, many rural communities in the country still lack access to electricity. Many of the unelectrified rural communities are either island communities on the Volta Lake, or remote off-grid communities, where grid extension is difficult and expensive. The Government of Ghana has targeted the installation of mini-grids to provide electrification for such communities as one of the ways to help achieve universal electrification. Government's Scaling-up Renewable Energy Programme is targeting the construction of 55 renewable energy-based mini-grids by 2020. A mini-grid may rely on a single power generation source or a mix of sources. Those that combine two or more power sources are referred to as hybrid systems. In this study, the viability of solar, wind, diesel and battery hybrid mini-grid systems for electrification in an island community in Ghana have been investigated based on techno-economic analysis.

Approach

The study was conducted in *Dodi Adjaade*, an island community in the Kwahu Afram Plains North District, with a population of about 5,230 people. The Kwahu Afram Plains North District is one of SNV's target districts for advocacy under the Voice for Change Partnership programme, specifically for mini-grids deployment as it is one of the few districts with significant number of Islands in the country. In order to achieve the objectives of the study, a survey was first conducted on the island to investigate existing and aspirational electricity demand of households, commercial/light industries, schools, clinics, street/community lighting and religious buildings. Solar radiation and wind speed data for the island was obtained from NASA Surface Meteorology and Solar Energy Database. Analysis was done using HOMER Pro Microgrid Analysis Tool.

Five configurations were modelled as follows:

- **Configuration A1**, consisting of a hybrid of *solar PV*, *storage batteries* and *diesel genset*;
- **Configuration A2**, which has similar hybrid arrangements as in Configuration A1, but supplying power only from 6am to 10pm.
- **Configuration B**, consisting of *solar PV* and *diesel genset* only;
- **Configuration C1**, consisting of *solar PV* and *storage batteries* only, with no capacity constraint (i.e. meeting the entire load plus reserve); and
- **Configuration C2** also consisting of *solar PV* and *storage batteries* only, but modelled with a 5% capacity shortage constraint in the system.

Results

The total annual electricity demand for Dodi Adjaade Island was estimated at 1,876,410 kWh/d, with a peak load of approximately 383 kW. About 94.1% of the demand is attributed to households, dominated by demand for television and refrigeration. Average annual per capita demand is estimated at about 359 kWh. This compares with per capita electricity consumption in Ghana in 2017, which was 417.5 kWh.

Configuration B, which is a hybrid of solar PV and diesel genset, has the lowest initial cost, net present cost (NPC) and levelized cost of electricity (LCOE), but the most expensive operating cost due to amount of diesel required to complement PV in meeting the load demand. This configuration corresponds to an initial capital of $958,000, an operating cost of $534,000/year, a total net present cost of $7,268,000 and a total cost of energy of 0.328 $/kWh. The optimal size of the system for Configuration B is 667 kW PV capacity and 460 kW genset. Notwithstanding the good economic indicators of Configuration B, it has the highest diesel consumption of the five configurations and therefore the lowest renewable fraction of 21.3%.

Configuration A1, which combines all three components of the system, i.e. solar PV, genset and storage batteries, is the second best system among the configurations meeting the full load in the community. The initial cost of $1,291,000 is slightly higher than that of Configuration B. The NPC and LCOE are also slightly higher that Configuration B, at 7,436,000 and 0.336 respectively. However, the operating cost is slightly lower, at $520,000, due to the relatively lower diesel consumption. Configuration A1 has a slightly higher renewable fraction of 29.5%, compared to the 21.3% obtained in Configuration B. Configuration A2, where power is supplied from 6am to 10pm only, has initial cost of of 1,140,000, NPC of of 6,216,000 and LCOE of 0.384.

Configurations C1 and C2 both have 100% renewable fraction, though costs are high. Configuration C1, for example, has battery requirements of 30,000 kWh, with an overall system initial cost of about $ 8 million. The NPC for C1 and C2 are $ 18,101,280 and $ 13,830,620 respectively, with LCOE at $ 0.818 and $ 0.658. LCOE for C1 and C2 are more than twice the LCOE for Configuration A1.

The cost breakdown of the five Configurations indicate that configurations with battery has battery costs as one of the principal costs of the system. For example, in Configuration C1, which is made up of only solar PV and storage batteries, battery costs make up 75% of capital costs and 99.64% replacement costs. For configurations with diesel genset, the cost of diesel is a significant driver of total costs. This is evident in Configuration B (solar PV and Genset only), where genset and its fuel contributes 85% of operating costs and 93% of replacement costs.

Approximately 50% of the households in the community are willing to pay up to $7.5 per month for electricity and 75% are willing to pay up to $5 per month. Sensitivity analysis of Configuration A1, the most cost effective configuration with all three hybrid components (i.e. *solar PV*, *storage batteries* and *diesel genset*), shows that costs are highly sensitive to electricity demand, cost of diesel and discount rate. A 100% capital cost subsidy decreases both net present cost and cost of energy by about 18%, suggesting that the systems have high operating costs.

Conclusions and recommendations

The lowest LCOE obtained among the configurations considered is 0.328 $/kWh (or 1.574 GHC/kWh). This is much higher than the existing March 2018 electricity tariff published by the Public Utilities Regulatory Commission (PURC) of 0.2768 GHC/kWh (more than 500% higher) charged to lifeline customers, and 0.5555 GHC/kWh (about 280% higher) charged to most residential customers in the 51-300 kWh/month (second tier) consumption bracket. As a matter of fact, the LCOE is 96% higher than the 0.8010 GHC/kWh charged to residential consumers in the highest tier, whose demand exceeds 600 kWh/month. Even at 100% capital subsidy, the LCOE of 0.277 $/kWh (equivalent to 1.330 GHC/kWh) is still high. The cost of energy obtained in the various configurations is however comparable to costs obtained in similar studies deploying similar configurations in several countries across the globe. Based on the conditions in the community, mini-grids as a business opportunity are not viable for the private sector.

Whereas public sector utilities have the luxury of cross-subsidisation for the operation of mini-grids, Ghana's mini-grid policy does not currently guarantee any compensation package for private sector players, even though they are required to charge only uniform tariffs. Without a compensation package to private sector players, they cannot charge uniform tariffs and remain in business, as lifeline tariffs may not be able to sustain even the operations cost of private sector mini-grids. Getting the right investment arrangement for private sector participation in mini-grids in Ghana depends on getting the right policies and regulations in place. The Government of Ghana is central to making mini-grids work well in the country. A focus on private sector participation would require lowering of operating risks faced by investors to help ensure a sufficient return, and this would happen if tariffs are dispassionately reviewed and made favourable to the private sector, or that there is a capital subsidy scheme that takes care of the shortfalls arising from the uniform tariff structure.

TABLE OF CONTENTS

CEESD

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Full meaning
ECG	Electricity Company of Ghana
FiTs	Feed-In-Tariffs
GSS	Ghana Statistical Service
HOMER	Hybrid Optimization of Multiple Energy Resources
KAPND	Kwahu Afram Plains North District
LCOE	Levelized Cost of Energy
NASA	National Aeronautics and Space Administration
NPC	Net Present Cost
PURC	Public Utilities Regulatory Commission
PV	Photovoltaic
RE	Renewable Energy
RE CSOs	Renewable Energy Civil Society Organisations
REMP	Renewable Energy Master Plan
SNV	Netherlands Development Organisation
SREP	Scaling-up Renewable Energy Programme
SSA	sub-Saharan Africa
VRA	Volta River Authority

1.0 INTRODUCTION

1.1 Background

It is the dream of most households of this world to have access to some form of electricity. Some people even consider access to electricity as a right which every citizen must enjoy (Brew-Hammond and Kemausuor, 2009). However, this right has eluded several millions of people, evident from global trends in access to electricity. The worst trends in access to electricity are found in sub-Saharan Africa and South-East Asia. In sub-Saharan Africa (SSA), about half of the population did not have access to electricity as at the end of 2016 (World Bank, 2019a). Only a few countries in the region, including Ghana, have relatively higher access.

As of 2018, Ghana generates a total of 3966.1 MW of utility scale power from mainly large hydro and thermal sources (Energy Commission, 2018). Renewables such as solar and biogas comprise 18.1 MW of this total aside large hydro. Peak electricity demand is around 2500 MW. According to the Ghana Grid Company (GRIDCO, 2019), peak electricity demand on 16th January 2019 was 2513.60 MW. The Ministry of Energy estimated access to electricity in Ghana at about 84% as at 2018 (Ministry of Energy, 2019), with the currently unelectrified population living in mainly rural communities. The definition of electricity access by the Ministry of Energy covers the entire population in a community that has access to the grid, irrespective of the number of households that have a connection (Mensah et al., 2014).

More than 30% of rural households do not have access to grid electricity, with most relying on torchlights and other flashlights for lighting. Many of the unelectrified rural communities are either island communities on the Volta Lake, or remote off-grid communities, where grid extension is difficult and expensive. Mini-grid solutions have thus been targeted to provide electrification for such communities as one of the ways to help achieve universal electrification in 2030. Ghana is already seen as a shining example when it comes to electrification in sub-Saharan Africa. Increasing electricity access to rural communities using mini-grids will continue to inspire other countries in the region where electrification is low.

Mini-grids are an ideal alternative to grid electricity in remote villages that do not have grid connectivity. Mini-grids are a mature and cost-effective technology solution, which have been shown to provide high quality and reliable source of electricity for lighting, communications, water supply, and motive power among others (USAID, 2011). Mini-grids are independent entities, they can be controlled and managed without connection to the conventional grid. Such distributed energy systems can potentially provide more reliable electricity, as any outages or interruptions to electricity supply can be quickly identified and corrected.

Additionally, having the site of power generation closer to the users also reduces distribution losses.

The use of mini-grids is often more pronounced and economical in communities that live in a core village with houses in proximity. Thus, the benefits of mini-grids as a source of energy are comparable to the national grid with a subtle distinction of the former being its independent nature.

The construction and operation of mini-grids is already underway in Ghana. As of 2018, more than 20 mini-grids have been constructed and are operational in the country. Five (5) out these mini-grids were constructed by the Government of Ghana and are public sector operated. The remaining mini-grids in the country are constructed and operated by the sole private sector player currently in the sector, Blackstar Energy. Going forward, more mini-grids are expected to be constructed by the government. In line with the global Scaling-up Renewable Energy Programme (SREP), the Government of Ghana developed an investment plan to facilitate its strategy to unlock financial opportunities with the view to accelerate the development of a sustainable renewable energy sector (Government of Ghana, 2015). The core projects envisaged by Ghana's SREP investment include the construction of 55 renewable energy-based mini-grids by 2020. The focus locations for mini-grids deployment are expected to be lakeside and island communities, where about 2.9 million of Ghana's population reside (Government of Ghana, 2015). Beyond the SREP, a draft Renewable Energy Masterplan is proposing the deployment of a minimum 300 mini-grids by 2030, though the estimated population to be connected is not stated. The deployment of mini-grids is aimed at (Energy Commission, 2019):

- Contributing towards universal access to electricity in remote and island communities;
- Improving socio-economic conditions of remote and island households;
- Providing access to cheaper and reliable power supply;
- Promoting productive uses of electricity; and
- Promoting electricity generation using local resources.

A mini-grid may rely on a single power generation source or a mix of sources. Those that combine two or more power sources are referred to as hybrid systems.

1.2 Aims and objectives of the study

In this study, the viability of solar, wind, diesel and battery hybrid mini-grid systems for electrification in Ghana have been investigated based on techno-economic analysis where the viability of optimal mini-grid configurations have been analysed. The aim is to generate evidence in the area of viable mini-grid configuration alternatives. The study focusses primarily on solar, wind, battery and diesel hybrids in the alternative system combinations as reflected by the current systems operating in the Ghanaian rural electrification space. Consequently, the results of the study will support the evidence-based advocacy activities of Renewable Energy Civil Society Organisations (RE CSOs) as well as inform policy makers, donor partners and other key stakeholders of the technical and financial viability of mini-grids in Ghana.

The specific objectives of the study were to:

I. Develop optimal mini-grid system configurations (solar, wind, battery and diesel) that are technically capable of meetig the determined level of demand
II. Evaluate the economic or financial viability of the optimal systems on the basis of different financial indicators.

2.0 BRIEF REVIEW OF LITERATURE

There are three broad categories of electrification options. These are: grid extension, mini-grid systems, and standalone systems (e.g. solar homes systems). Mini-grid and standalone systems may also be classified into one category as off-grid systems. Both grid-connected and off-grid systems have advantages and disadvantages, but the choice between them for a particular community largely depends on cost, which is itself driven by several factors. The cost of a particular electrification technology to a community depends on the distance to the closest point on the national grid, the population density, electricity demand and resource availability (Kemausuor et al., 2014). In communities with scattered households, a combination of these options may be possible. For example, households in a mini-grid designated community that are farther away from a community cluster may be provided with standalone systems if that proves to be the most cost-effective option. This section briefly reviews mini-grid systems, the need for hybrid mini-grids, some of the advantages that mini-grids offer and some mini-grid configurations from previous studies.

2.1 Mini-grid electrification

Mini-grids comprises of a power generator and a low-voltage distribution network often serving a single community or small town. The most common technologies used for electrification with a mini-grid are diesel generators, small hydro systems, photovoltaics, wind power and biopower. These technologies can be combined in a configuration of two or more to form a hybrid system. Mini-grids are independent of the national grid and are designed to meet the load of the candidate location, though they may also be used as a transition step to build sufficient demand to make grid connection cost effective. In view of this, the regulatory authority could insist that mini-grids are constructed in a way that makes it possible to integrate the system into the main distribution grid when it arrives in a community. The total capacity of the mini-grid technology depends on the annual load hours of the candidate community, the capacity factor of the technology(ies) and distribution losses (Palit and Chaurey, 2011). Many studies have shown that renewable mini-grid technologies have large potential in sub-Saharan Africa and could contribute towards attaining universal access to electricity in the region (Ayamga et al., 2015; Azimoh et al., 2017, 2016; Dagnachew et al., 2017; Ketlogetswe and Gandure, 2018; Moner-Girona et al., 2018; van Ruijven et al., 2012).

2.2 Resource constraints and need for combining technologies in hybrid installations

Among the various renewable energy resources and technologies available on the market currently, solar and wind energy systems are considered as promising power generating sources due to their availability and topological advantages in remote areas (Giannoulis and Haralambopoulos, 2011; Lau et al., 2010). However, wind and solar are intermittent or have high variability, though solar may be fairly predictable, as it is often available during certain hours of the day, and completely out at night. The intermittency constraints in solar and wind require the use of large capacity sizes of solar PV panels or wind turbines and expensive storage systems, in order to meet electricity demand. These constraints are mitigated with the use of hybrid systems, so that different resources complement each other. The intermittency in solar and wind resources can be mitigated to a large extent via an optimal integration of these resources to meet a particular load for extended time periods (Haghighat Mamaghani et al., 2016). The use of solar and wind energy systems is becoming more economically justifiable and technically feasible owing to cost reduction in manufacturing and extensive research and development of their technologies for power generation, as well as decreasing costs and increased efficiency of power storage (Shafiullah et al., 2012). Apart from solar and wind hybrid systems, other systems requiring more than two technologies, such as PV-wind-diesel systems are also used, in order to provide even more reliability. Several types of hybrid systems can be utilized, such as PV-diesel generator system, PV-Energy Storage System, PV-Hydropower system, etc., depending on resource availability in the candidate location, in order to enhance mini-grid deployments and make them more reliable and affordable (Rabetanetiarimanana et al., 2018).

2.3 Advantages of hybrid configurations

In remote locations, where no electric grid is available, the first short-term solution can be the diesel generator. However, these systems may suffer from high cost of maintenance, fuel supply and considerable amount of pollutants or emissions, thus justifying the need for hybrid systems, either with or without diesel. The main advantage of hybrid systems is that they supply energy from different sources, increasing reliability of supply. A summary of the benefits of hybrid mini-grids is presented in Table 1.

Table 1: Benefits of hybrid mini-grids

Benefit category	Benefits	Description
Technical/ operational	Improved electrical services	Hybrid mini-grids can offer improved electrical services to the customer compared to traditional single-source systems. Hybrid systems have at least partial redundancy, and the PV-Battery combination provides the opportunity to supply low load overnight, which is typically unserved by strictly diesel systems due to inefficiency at low load. Improved electrical services also achieved via the fast rollout of services to unelectrified areas, provision of additional power over that available from individual systems, or to areas where fuel is not available.
	Reduced fuel Dependence	With the increased Renewable Energy use, diesel fuel consumption is reduced, and the diesel generator may not need to be run when combined with battery storage (which lowers efficiency). The inclusion of Renewable Energy generators therefore reduces operating costs but also reduce reliance on an often uncertain supply chain, and volatile commodity prices, and can therefore benefit service reliability as well as reduce price risk.
	Reduced maintenance Costs	As above, the reduced need for the diesel generator will mean the run hours of the generator will accrue at a lower rate. Also, by not being required to service low loads the generator lifetime would increase.
Financial	Improved LCOE for operators	The levelised cost of electricity for mini-grids is often lower than that of grid extension to remote areas and can be optimised by a combination of different technologies.
	Increased satisfaction	Due to an improvement in electrical services (e.g. less blackouts) customers have demonstrated greater satisfaction with energy services.
Social	Opportunity for rural economic development	A shortcoming of SHS technology is the inability to service larger loads, including those required for many types of income generating activities. Hybrid mini-grids offer significantly greater power, continuity and reliability to serve these loads. It has also been observed that some implementation models for operating hybrid mini-grids can economically benefit the community directly through creation of jobs or entrepreneurial opportunities.

	Strengthening Community	Access to electricity contributes to a whole raft of social benefits, such as improved healthcare, communication and standard of living. Also attributed to hybrid mini-grids is the potential for improvements in community cohesion to arise, and compared to the use of individual solar home systems or private gen-sets.
	Local capacity Building	Where capacity development is incorporated, hybrid mini-grids implementation can contribute to increases in local skills and build new community institutions. Models of community ownership have also been developed whereby the end users are also the owners and operators of the system, this ensures incentives are aligned
Environmental	Environmental Protection	By reducing combustion of diesel, hybrid systems reduce greenhouse gas emissions and improve local air and noise pollution.

Source: summarised from (Hazelton et al., 2014)

2.4 Review of some mini-grid configurations

In literature currently, a number of studies have been conducted on mini-grids across the globe. The energy planning and modelling tool, HOMER, which is described in detail in Chapter 3, has emerged as the modelling tool of choice for hybrid mini-grids. HOMER has been widely used in mini-grid studies (Erdinc and Uzunoglu, 2012). A plethora of academic literature exist on HOMER's application within Africa and other regions and has emerged as the most used energy planning tool within the mini-grid sector, compared to other tools (Kemausuor et al., 2018). Countries where hybrid mini-grid studies have been done on the African continent include Burkina Faso (Ouedraogo et al., 2015), Cameroon, (Kenfack et al., 2009; Nfah, 2013; Nfah and Ngundam, 2009), Ethiopia (Bekele and Palm, 2010; Bekele and Tadesse, 2012; Bekelea and Boneya, 2012; Braun and Girma, 2013), Kenya (Sigarchian et al., 2015), Mauritania (Dia et al., 2014) and Mozambique (Garrido et al., 2016), Algeria (Himri et al., 2008) and Uganda (Kimera et al., 2014; Mechtenberga *et al*., 2012; Murphy et al., 2014; Twaha et al., 2012).

In Ghana, Adaramola et al. (2014) conducted an economic analysis of the feasibility of using a hybrid system of diesel generators, solar PV, wind turbine and storage battery for Adafoah, a community in the Greater Accra Region. The renewable energy contribution varied from 47% (for PV–wind–generator, which was the most viable system) to 17% (in the case of PV–generator system), with levelized costs of $0.276/kWh and $0.281/kWh for PV-wind-generator system and PV-wind-generator-battery respectively. Wind speeds in the study area were quite high, favouring a higher wind penetration in the system with wind turbines. The study did not conduct any load assessment in the community, rather, it used the Ghana average per capita consumption of 5 kWh/day.

Table 2 presents a list of some modelled configurations found in literature focused on the techno-economic feasibility of mini-grids in terms of their optimal configurations. The table also lists the study locations and references. As can be seen in the reviewed configurations in Table 2, the LCOE of $0.08/kWh represents the lowest LCOE recorded by an optimal configuration of hydro power, wind turbine and diesel generator in a South African village (Azimoh et al., 2016). Admittedly, this is one of the lowest mini-grid hybrid configuration LCOEs encountered in literature. With regards to the highest, an LCOE of $7.619/kWh was recorded by an optimal configuration of Wind turbine in a study in Colombia (Haghighat Mamaghani et al., 2016). Again, this LCOE in Colombia is about the highest encountered in literature seen to date. The study concedes, however, that wind speeds in the study region are too low to make energy generation from wind turbines profitable, which may have contributed to the high LCOE.

Table 2: Examples of some configurations modelled in different countries and regions

Location	Tool used	Optimal Configuration	Levelized Cost ($)	Source
Colombia (Puerto Estrella)	HOMER	Diesel system	0.868	(Haghighat Mamaghani et al., 2016)
		Solar system	0.527	
		Wind system	1.659	
		Solar Wind Hybrid system	0.557	
		Solar Diesel Hybrid system	0.463	
		Wind Diesel Hybrid system	0.805	
		Solar Wind Diesel Hybrid system	0.473	
Colombia (Unguia)	HOMER	Diesel system	1.000	
		Solar system	0.522	
		Wind system	7.619	
		Solar Wind Hybrid system	0.563	
		Solar Diesel Hybrid system	0.444	
		Wind Diesel Hybrid system	1.000	
		Solar Wind Diesel Hybrid system	0.465	
Colombia (Jerico)	HOMER	Diesel system	1.000	
		Solar system	0.481	

		Wind system	2.193	
		Solar Wind Hybrid system	0.516	
		Solar Diesel Hybrid system	0.448	
		Wind Diesel Hybrid system	0.898	
		Solar Wind Diesel Hybrid system	0.477	
Bangladesh	HOMER	PV/Biomass/BESS	0.203	(Islam et al., 2018)
		PV/Biomass/DG	0.21	
		PV/Biomass/BESS/DG	0.188	
South Africa Thlatlaganya Village	HOMER	DG/PV/Wind	0.41	(Azimoh et al., 2016)
South Africa Lucingweni Village		Hydro power/Wind/DG	0.08	
Bangladesh	HOMER	DG/PV/Batteries	0.368	(Bhattacharyya, 2015)
		DG/Wind/Batteries	0.375	
		DG/PV/Wind/Batteries	0.463	
		DG	0.379	

3.0 STUDY APPROACH

3.1 Study area

Dodi Adjaade, an island community in the Kwahu Afram Plains North District (KAPND) was selected for this study (see Figure 1). The Kwahu Afram Plains North District is one of SNV's target districts for advocacy under the Voice for Change Partnership programme. Advocacy in this district is specifically on facilitating mini-grids deployment as the district one of few areas with significant number of islands in Ghana.

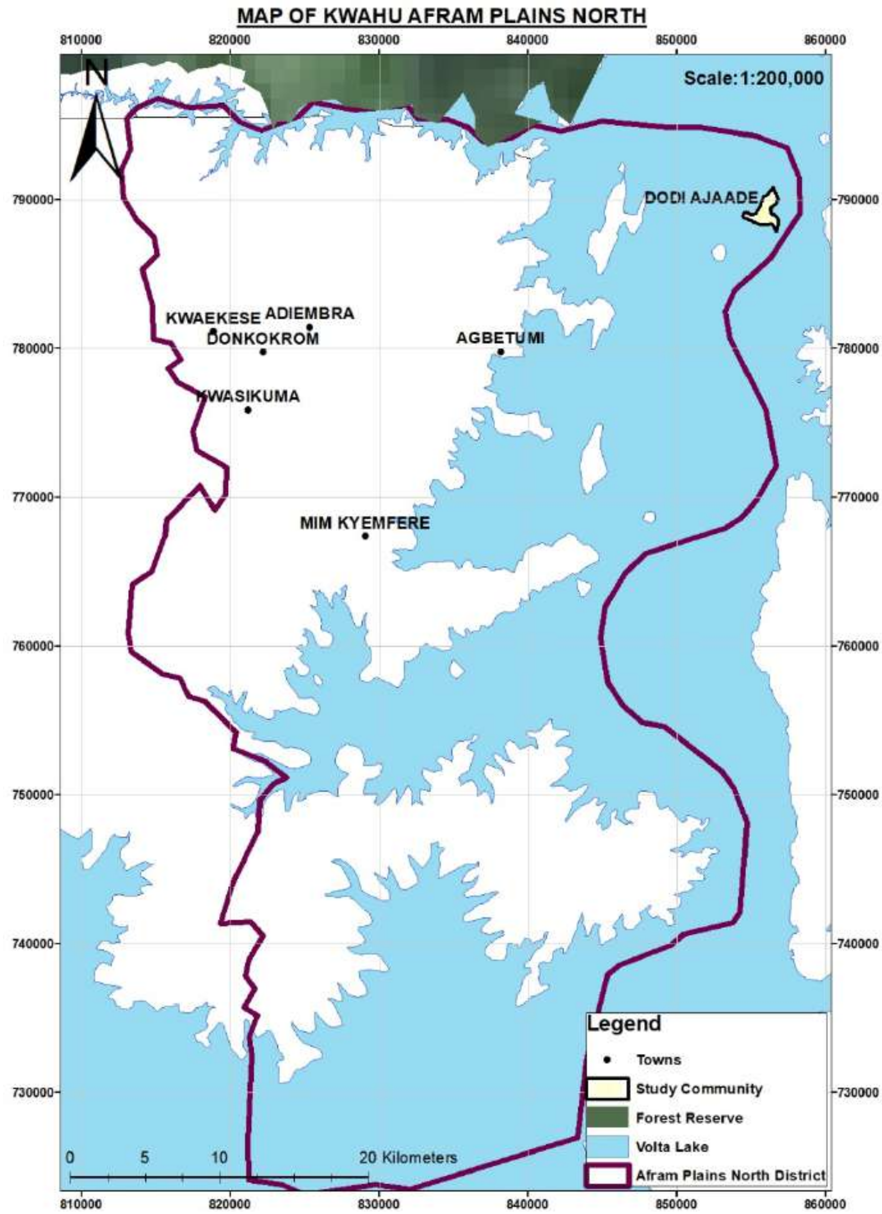

Figure 1: Map of Kwahu Afram Plains North showing island

The selection of the island was done jointly by the KAPND Assembly officials, SNV officials and CEESD (the NGO implementing the V4CP programme at the district). The island was selected because it is one of the largest unelectrified islands in a district that has a lot of islands that remain unelectrified. The latitude and the longitude of Dodi Adjaade are 7° 7'58.64"N and 0°13'22.80"E respectively. Dodi Adjaade is located on the northeast side of the district.

The island is made up of seven suburbs, namely; *Kuvetoe*, *Voodukope*, *Abgeve*, *Zongo*, *New Town*, *Ningo Town* and *Galito*, with Kuvetoe regarded as the center of the island. The entire island covers an area of about 20 ha[1], and falls within the savannah vegetation zone. With regards to climate conditions, high average temperature of 36.80 ^{0}C is experienced during the hot season and the lowest temperature of about 19.09 ^{0}C during the colder seasons (Ghana Statistical Service, 2013). The land is generally undulating and rises about 80 meters to 95 meters above sea level. The island is surrounded by the Volta Lake which serves as a means of transport to both inland and other island communities. The Volta Lake also serves as water source for domestic and agricultural purposes.

According to the Chief, Queenmother, Assembyman, and the Headteacher of the public basic school in the community, the total population of *Dodi Adjaade* is about 5,230 with the number of households estimated at 589, suggesting an average household size of between 8 and 9 persons. Five of the suburbs have clustered households whereas one of them, *Galito*, has households that are somewhat scattered. The household structure is mainly a combination of primary and extended family members with a youthful population dominance representing a major potential for the community in terms of labour availability. In terms of utility and household facilities, solar lamp and torch/flashlight are the main sources of lighting, with about 25 households having solar standalone installations (See Figure 2). Wood fuels are the main source of energy used for cooking with a few of the households using LPG purchased from Abotoase, the closest inland town.

[1] Area captured with a GPS device during the community survey

Figure 2: PV Panels for charging lanterns and home systems

Fishing and its processing constitute the main occupation of the community and serves as their main source of income. Several other seasonal businesses are found in the community, including farming and transportation through the use of medium sizedboats forfor transporting people and goods to the inland town for trade. Other businesses in the community includes; construction, cosmetic manufacturing (soap and body cream), art work, grocery stores, drinking bars, fashion and milling. Women constitute the majority of service and sales workers, as well as craft and related trades. Milling machine, frozen foods, drinking bars and video centre businesses are singled out to be the most important business in terms of energy consumption (see Figure 3). The community expects to see an increase in small scale businesses involving frozen foods, mini market and drinking bars if electricity is provided to the community. The possibility to freeze and preserve fresh fish (fish storage) is a key business opportunity that the community would want to explore when given electricity. Some notable pictures taken from the community are shown in Appendix 1.

Two (2) commercial enterprises in the community were identified to have installed relatively larger solar systems. One of them was a grocery shop which uses the solar system to power refrigerators for the sale of cold drinks. The second commercial enterprise identified to be using a solar system was a drug store or chemical shop. Religious bodies and some other commercial enterprises use petrol or diesel generator for electricity. The communities lack access to stable telecommunication. Leaders of the community pointed out that due to the lack of electricity access, migration is common among the youth who move to the nearby town *Abotoase* which is connected to the national grid. Abotoase is an hour's boat ride away from Dodi Adjaade by motor powered boat on the lake.

(a)

(b)

(c)

(d)

Figure 3: Some businesses in the community

(a) Drinking bar's refrigerator (b) Grinding mill (c) Over the counter chemical store (d) Provisions shop

3.2 Community survey and data acquisition

A reconnaissance survey was conducted to observe the community and gather basic population, household and other relevant information that would inform electricity demand estimation. The demand sectors identified during the reconnaissance survey were households/residential, commercial/light industrial, schools, clinic and religious buildings with details as follows:

i. ***Household/Residential demand***: include private households where energy is consumed primarily for lighting and as input for the provision of services (including room conditioning, refrigeration, entertainment/communication, etc.) from a range of electricity consuming appliances such as radios, sound systems, refrigerators, fans, television, mobile phones etc.

ii. **Commercial/Light industrial demand**: represents the potential electricity to be consumed by commercial facilities such as grinding mills, mini-shops, drinking bars, over the counter chemical stores, fish storage, ice-making, irrigation, etc.

iii. **Schools, clinics and religious bodies demand**: represents the consumption of energy used in mosques, churches, schools and health centres in the community.

iv. **Street/Community lighting demand**: represents electricity consumed by street and community lighting systems that provide lighting to certain vantage points during the night.

Following the reconnaissance survey, a data collection survey was then conducted to establish current and expected/future electricity demand of the different demand sectors identified in the community. Practically, all demands for the use of electricity is expected in the future. Even the households with solar standalone systems use it for mainly basic lighting, which means appliances such as television, fans and refrigerators are expected/future appliance demand for such households. Five types of questionnaires were designed to cover each of the five demand sectors identified, i.e. households, commercial/light industrial, schools, clinics, and religious bodies. Details of the questionnaire are provided in Appendix 2 to Appendix 6. Street and community lighting were estimated.

Statistical sampling for the households was done using equation 1 (Ayamga et al., 2015).

$$n = \frac{N}{[1+N(e)^2]} \quad (1)$$

where n is the sample size, e is the margin of error which was taken as 10%, N is the total number of households in the community = 589.

Based on Equation 1, the minimum number of households to be interviewed was computed as eighty-five (85). However, because of the enthusiasm of community members to participate in the survey, one hundred and sixty (160) households were interviewed. Beginning with the very first household as one enters the community, every third to fifth household was selected for the interview until the minimum 85 households were interviewed. Subsequently, all households that were available and willing to participate in the survey during the period were interviewed. The other demand sectors were entirely covered in the survey, i.e., all commercial/light industrial facilities, all schools, all religious buildings, and the only community based health centre in the community were surveyed. During the survey, GPS coordinates of interview points were picked with a GARMIN *eTrex® 10* Handheld Outdoor GPS device. A map of the respondents is shown in Figure 4.

The survey investigated the various electrical appliances and equipment owned by the households and other sectors, and included appliances that they will want to own in the future when the community is provided with electricity. In addition, the power ratings and daily usage hour of the electrical appliances and equipment were investigated.

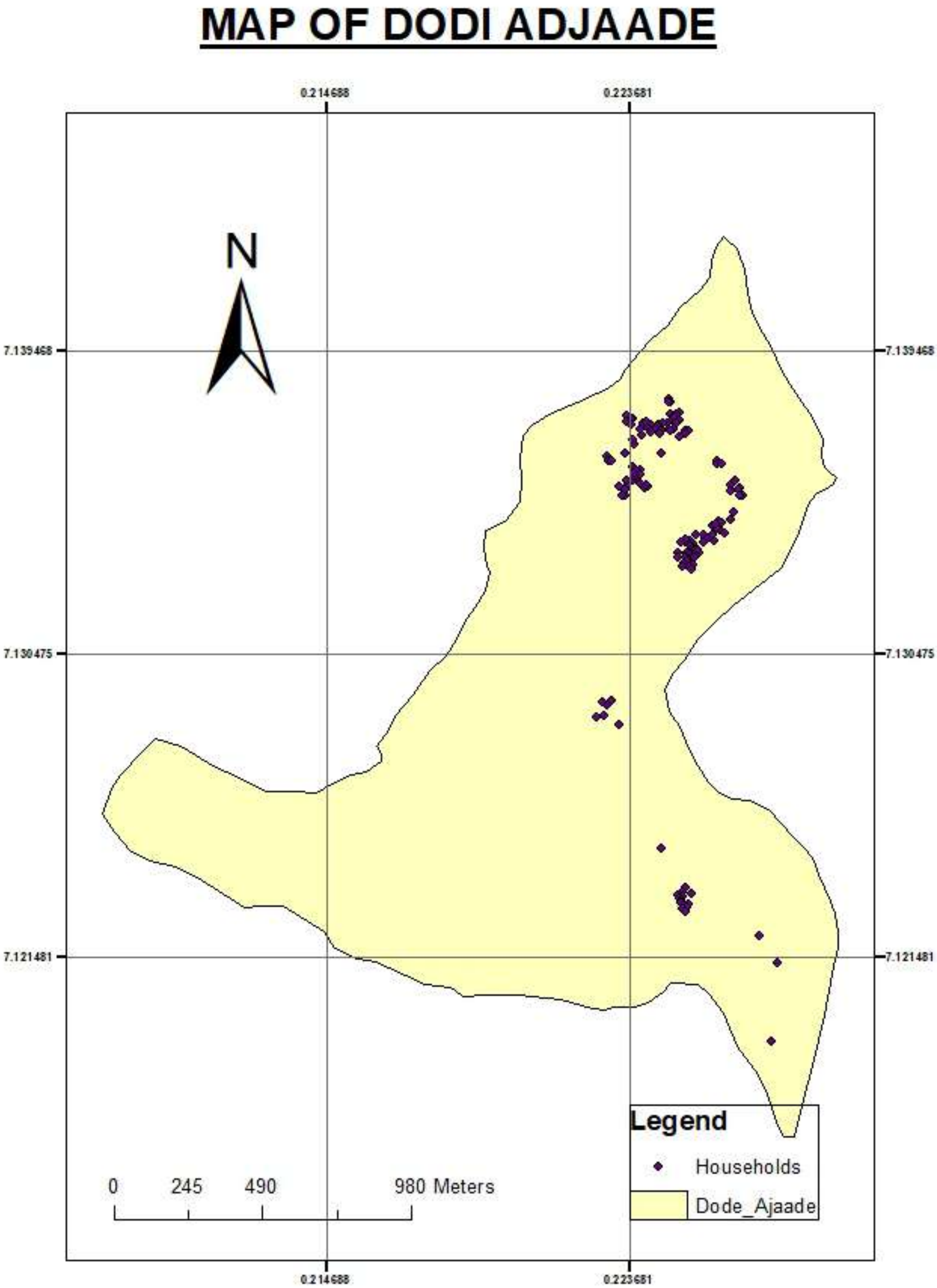

Figure 4: Map of community showing respondent locations

3.2.1 Community load calculation

The electricity demand was calculated using equation 2.

$$P_L = \sum_i^n (P_i \times N_i \times t_i) \quad \textbf{(2)}$$

where P_L is the primary load (kWh/d), P_i is the power rating of appliance *i* (W), N_i is the total number of appliance *i*, and t_i is the time of use of appliance *i* (h/d). Factor *n* is the total number of appliance categories.

The following assumptions were made in the estimation of loads, especially for weekend and seasonal loads:

- Commercial loads estimated from the survey were doubled for the final analysis, to address sudden interest in new business start-ups if electricity becomes available;
- There will be no daytime school loads on weekends, from approximately 6am to 6pm. Weekend school loads will only be for outside lighting at night;
- High wattage church musical instruments are only used on weekends during church service, according to responses from the survey;
- During school holidays, there will be no school loads during the day. Holiday loads will only be for outside lighting at night. The 2018/2019 Ghana Education Service basic school calendar was used in estimating holiday periods, though there could be minor annual variations; and
- In the main rainy season, which was roughly assumed to last from May to September (though there may be slight variations), cooling loads were halved, since the period is generally cooler, especially for an island community.

3.2.2 Resource assessment

The resources considered in this study for electricity generation, in line with the objectives, are solar, wind and diesel. Diesel fuel is readily available in Ghana, though, unlike renewable energy resources, it is not free. Currently, the price of diesel in Ghana is GHS 4.95/*l* (approximately $1.03/*l*). Diesel can be sourced from Abotoase, the closest inland community, about an hour's boat ride from the community.

The solar irradiation of the community was taken from NASA Surface Meteorology and Solar Energy Database (NASA, 2018). The monthly radiation and clearness are shown in Figure 5. From Figure 5, it is clear that the solar radiation for the selected community is available practically throughout the year. The average monthly solar radiation level in the community is

5.083 kWh/m^2/day, translating to an annual potential of approximately 1,855 kWh/m^2/yr. The radiation level rises between October and April and reduces during the major rainy season from May to September. The number of peak sunshine hours in the region averages between 4 and 4.5 hours per day.

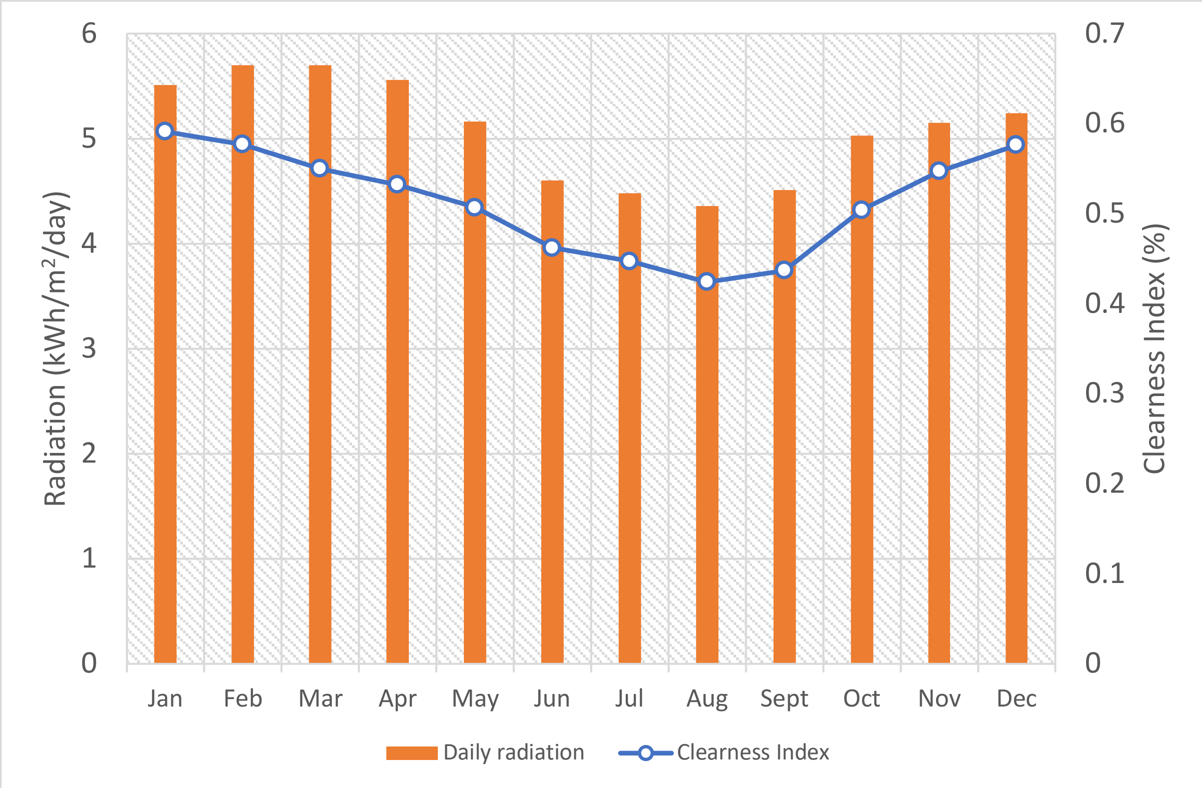

Figure 5: Monthly average solar radiation and clearness index

Source: (NASA, 2018)

The wind speed of the community was also taken from NASA Surface Meteorology and Solar Energy Database (NASA, 2018). The average monthly wind speed in the community is about 3 m/s at 50 m height (as shown in Figure 6), which is not very good for wind power generation. This level of wind speed is generally considered as poor, and not optimal for wind power generation (Essandoh and Osei, 2014). Wind speeds in Ghana are generally not high. Relatively higher wind speeds are found along the coast of the country. Due to the very low wind speeds in the community, wind turbines were not considered in modelling of the systems. A trial run indicated that the contribution of wind was not significant, leading to the decision to finally delete it from the system configurations.

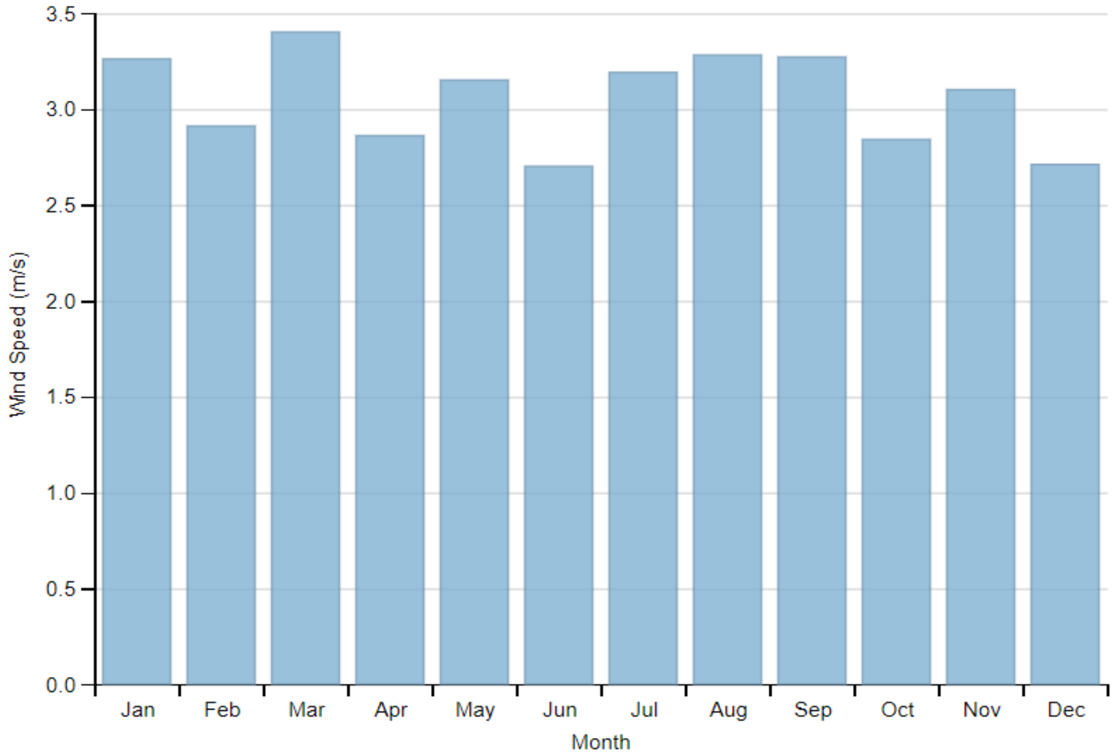

Figure 6: Monthly average wind speed data for Dodi Adjaade

3.3 Description of HOMER Pro Microgrid Analysis Tool

Modelling of the system was done using HOMER Pro Microgrid Analysis Tool. The 'Hybrid Optimization of Multiple Energy Resources' (HOMER) model was developed by the National Renewable Energy Laboratory in 1992 (Kemausuor et al., 2018). The flagship product is HOMER Pro, which is used for optimising microgrids and distributed energy. Other diversified products of HOMER include HOMER Grid, HOMER QuickStart, HOMER Quickgrid and two open architecture supporting application programming interfaces: SaaS and Controller. It is one of the most widely used computer software modelling tools for simulating, designing and analysing off-grid and grid-connected power systems involving many combinations of conventional generators, wind turbines, PV arrays, run-off river hydropower, biomass power plants, micro-turbines, hydrogen storage, batteries, combined heat and power, fuel cells, boilers, electrolysers, AC/DC bi-directional converters and others, to serve both thermal and electric loads. The optimization capability of HOMER allows the user to easily evaluate the technical and economic viability of existing and proposed RE technologies with a consideration of factors such as cost of technology and the availability of the energy resource.

The ‘HOMER Pro’ version (referred simply to as ‘HOMER’ subsequently) was used to model the hybrid (solar PV, diesel generators, batteries) mini-grid system, in line with the study objectives. The software was used to perform techno-economic analysis of the optimal hybrid system configurations using the electricity demand obtained from the community. HOMER ranked the optimal mini-grid system configurations based on NPC, LCOE, capital costs and operating costs. The schematic layout of the methodology adopted in HOMER is shown in Figure 7. The interface of the software is also shown in Figure 8.

3.3.1 Simulation method in HOMER

HOMER software performs three main tasks: simulation, optimization, and sensitivity analysis (Islam et al., 2018). Firstly, it checks whether the system is feasible. A system is considered feasible if it can sufficiently satisfy the electricity demand considering any restrictions imposed. At this stage, HOMER performs an hourly time series simulation for the whole period of one year, computing the presented renewable power, comparing it to the electricity demand, and determining the action of doing what with additional renewable power in times of surplus, or how best to produce extra power in times of shortage (Lambert et al., 2005). It also determines the life-cycle cost of the system at this stage. As indicated in the load calculation, the time variation of demand was considered. Thus, there was separate demand for weekday and weekend, as well as seasonal variations in the demand.

As a second objective, it finds the optimal value of the input variables over which the system designer has control such as the combination of components and the size or quantity of each. In this optimization process, HOMER simulates various system configurations under user-specified constraint, rejects the infeasible ones, ranks the feasible ones according to NPC and represents the lowest NPC system as the optimal system configuration.

Finally, in the sensitivity analysis process, HOMER simulates several optimizations under a range of input variables to measure the effects of uncertainty or changes in the system.

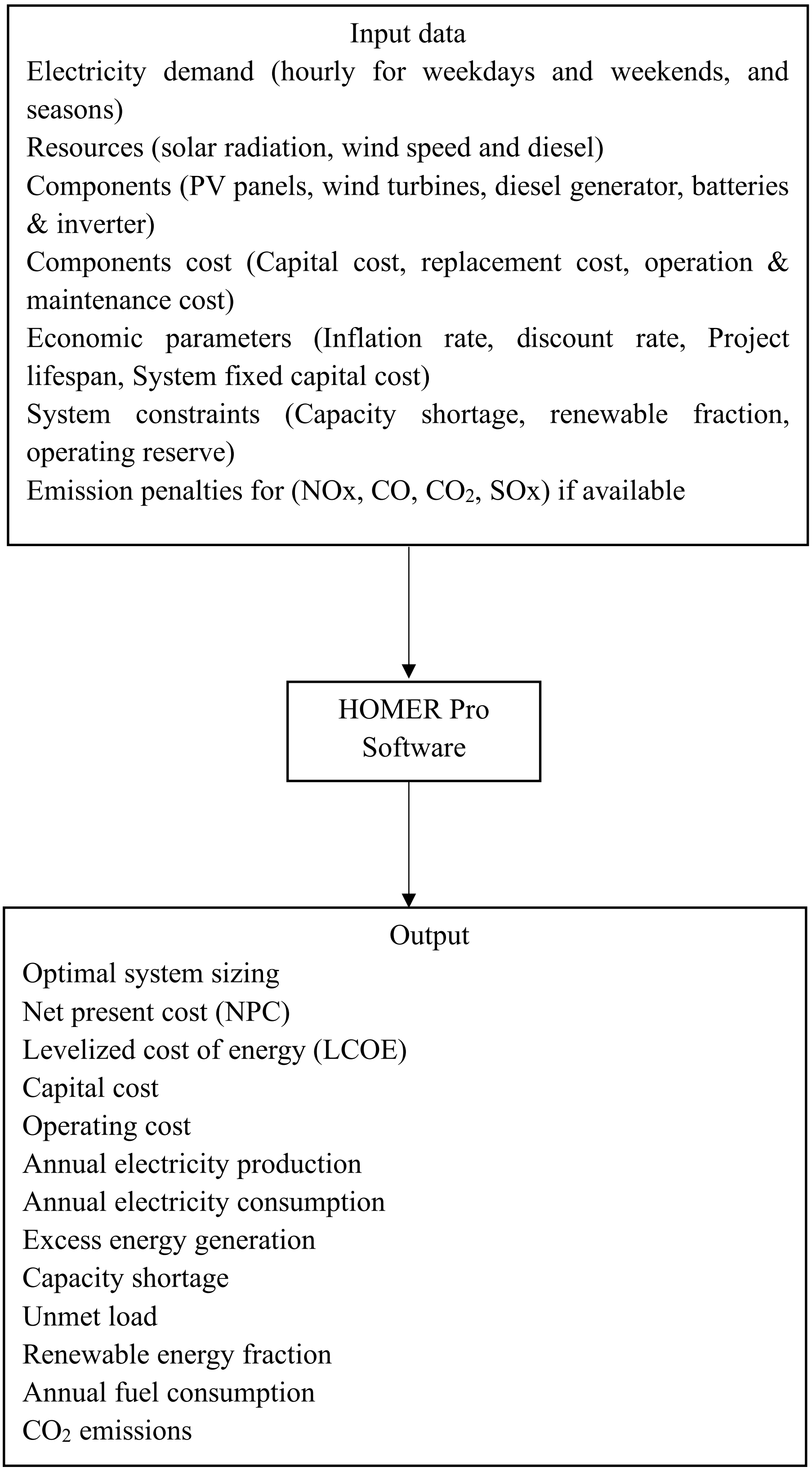

Figure 7: Schematic layout of HOMER software analysis

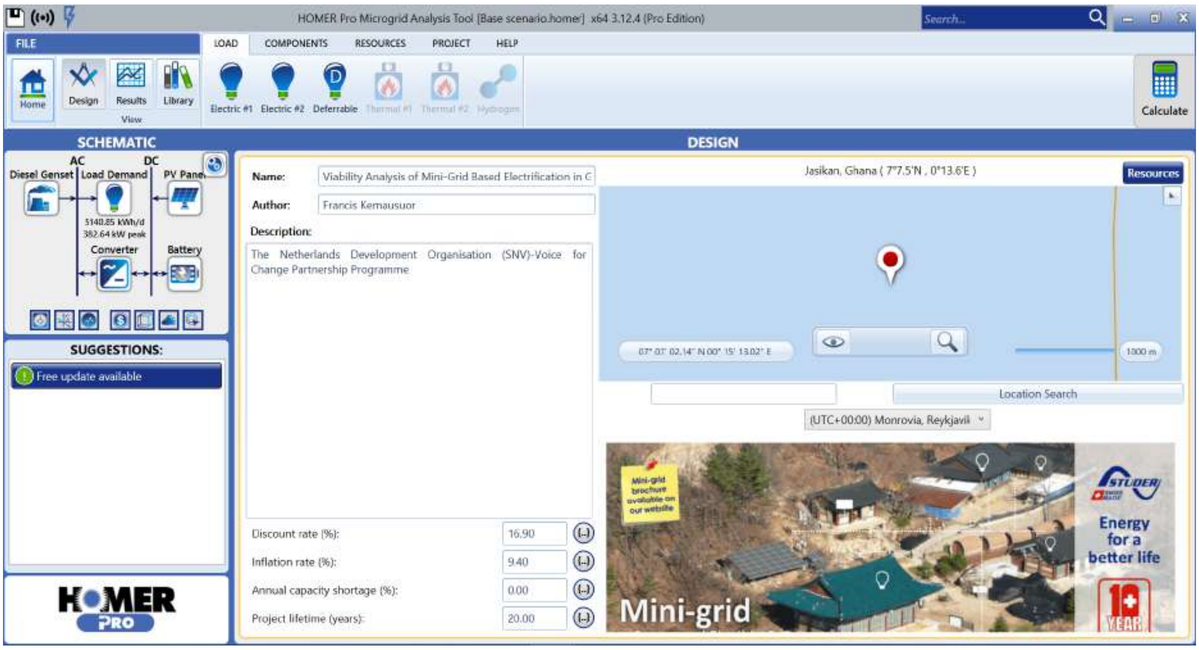

Figure 8: Interface of HOMER Pro Microgrid Analysis Tool

3.4 HOMER software input data

HOMER software requires input data such as electricity demand, renewable resource (e.g. monthly solar radiation), component types (PV module, diesel generator, battery, converter), component cost details (capital, replacement, operation and maintenance), lifetime of components, economic parameters (discount rate, expected inflation rate, project lifespan, system fixed capital cost and capacity shortage penalty), system constraints (maximum annual capacity shortage, minimum renewable energy fraction, operating reserve) and emission penalties to perform simulation and optimization of the proposed hybrid power system. The capital cost is the initial purchase price of components, the replacement cost is the cost of replacing the component at the end of their lifetime and the operating and maintenance cost is the annual cost of operating and maintaining the component. Cost parameters and other economic input data are provided in Table 3 and Table 4.

The components of each system were chosen based on the system composition and configuration. Cost information for solar PV and accessories (such as batteries, inverters, installation costs) were obtained from Process and Plant Automation Ghana Ltd. and Aeko Solar. All the systems considered in this study will have different lifespan based on manufacturer's specification and local conditions, with a project life considered as 25 years, following trend in recent analysis (Oviroh and Jen, 2018; Bhattacharyya, 2015), with the assumption that solar PV panels will last for approximately 25 years under local conditions. Systems with less than 25-year lifespan will be replaced when due. Replacement costs have been provided in the model.

Table 3: Components financial inputs parameters for configuring optimal hybrid mini-grid system

Component	Capital Cost	Replacement Cost[a]	O&M Cost
PV Panel	$1000/kW[b]	$0/kW	$8/kW/year[c]
Diesel Genset	$275/kW[d]	$200/kW	$0.01 /op.h[c]
Battery	$200/kWh[b]	$150/kWh	$4/kWh/year[c]
Converter	$300/kW[b]	$250/kW	$4/kW/year[c]

[a]Replacement costs are estimated based on market trends and technological development
[b]Data collected from Process and Plant Automation Ghana Ltd. and Aeko Solar in Ghana
[c]Assumption based on characteristic performance of the component and suggestions from HOMER, based on experience in other projects
[d]Data collected from Mantrac Ghana
[e]Data collected from international market
Op.h – operating hours

Table 4: Summary of economic input parameters

Parameter	Value	Source
Nominal Discount rate (%)	16.9	(Bank of Ghana, 2019)
Real Discount rate (%)	6.86	Computed in HOMER using Fisher equation
Expected Inflation (%)	9.4	(Bank of Ghana, 2019)
Project lifetime (years)	20[a]	
Distribution cost ($)	50,000[b]	(TTA, 2017)
Distribution System O&M Cost ($/year)	1,500[c]	

[a]Typical project lifetime used in other projects are 20-25 years
[b]Cost needed for the development of mini-grid distribution. Computed using an estimated inter-household distance of 20 m. Cost of distribution line per metre was obtained from the government mini-grids developer, TTA
[c]Estimated cost of maintaining distribution system.

3.5 Solar PV modules design in HOMER

The solar cells inside the PV panels convert the sunlight into direct current (DC) through a process called photoelectric effect. The PV module will be installed on the ground on a fixed axis. The PV panels will be mounted at a slope equal to the latitude value of the chosen location to capture maximum solar radiation. The PV panel azimuth angle is zero and the PV panels will be oriented towards the south. The lifetime of the PV panels is considered as 20-25 years, though 25 years was used for the design. There will be no tracking of the PV panels. The derating factor which accounts for losses due to temperature effect, dirt, wire losses, shading, aging etc. is taken as 80%, which means that the panel will produce 20% less power than the nominal. In addition, ground reflectance of 20% is considered for analysis. Detailed specification of the solar PV panel is provided in Table 5. HOMER calculate the power output (PV_{output}) of the PV array using equation 3 (Lambert et al., 2005; Adaramola et al., 2014):

$$PV_{output} = C_{PV} D_{PV} \left(\frac{\overline{I_T}}{I_{T,STC}}\right) \left[1 + \alpha_p (T_c - T_{c,STC})\right] \quad (3)$$

Where C_{pv} = is the rated capacity of the PV module in (kW) under standard test conditions, D_{pv} = PV derating factor (%), $\overline{I_T}$ = solar radiation incident on the module surface (kW/m^2), $I_{T,\ STC}$ = incident solar radiation at standard test conditions (1000 W/m^2), α_p = temperature coefficient of power (%/^{o}C), T_c = PV cell temperature in ^{o}C and $T_{c,\ STC}$ = PV cell temperature under standard test conditions (25 ^{o}C).

Table 5: Technical specification of solar PV panel

Parameter	Specification
Nominal Maximum Power (Pmax)	300 W
Maximum Operating Voltage (Vmp)	32.6 V
Maximum Power Current (Imp)	9.21 A
Open Circuit Voltage (Voc)	40.1 V
Short Circuit Voltage (Isc)	9.72 A
Module Efficiency	18.33%
Operating Temperatures	-40 °C ~ +85 °C
Temperature characteristics	
Temperature Coefficient of Pmax	-0.39 %/°C
Temperature Coefficient of Voc	-0.29 %/°C

Temperature Coefficient of Isc	0.05 %/°C
Nominal Operating Cell Temperature	45±2 °C

3.6 Battery specification and cost data

Due to the fact that solar PV electricity is only generated during the day, solar PV electricity system require battery storage facilities in order to ensure a constant power supply, to complement diesel systems. The characteristics of the battery are shown in Table 6. The battery will be used to store excess energy generated from the power system to meet the electricity demand of the community whenever there is an intermittency and non-availability of power supply from the other sources. HOMER software calculates the storage bank autonomy A_{batt} and the battery lifetime R_{batt} using equations 4 and 5 (HOMER Energy, 2016; Lambert et al., 2006).

$$A_{batt} = \frac{N_{batt} V_{nom} Q_{nom} \left(1 - \frac{q_{min}}{100}\right)\left(24 \frac{h}{d}\right)}{L_{prim,ave}\left(1000 \frac{Wh}{kWh}\right)}$$

(4)

Where: N_{batt} = number of batteries in the storage bank; V_{nom}= nominal voltage of a single storage (V); Q_{nom}= nominal capacity of a single storage (Ah); q_{min}= minimum state of charge of the storage bank (%); $L_{prim,\ ave}$= average primary load (kWh/d)

$$R_{batt} = \min\left(\frac{N_{batt} Q_{lifestime}}{Q_{thrpt}}, R_{batt,f}\right)$$

(5)

Where N_{batt} represents number of batteries in the battery bank, $Q_{lifetime}$ the lifetime throughput of a single battery, Q_{thrpt} the annual throughput (the total amount of energy that cycles through the battery bank in one year), and $R_{batt,f}$ the float life of the battery (the maximum life regardless of throughput).

Table 6: Technical specification of storage battery

Nominal Voltage	12 V
Nominal Capacity	1 kWh
Maximum Capacity	83.4 Ah
Capacity Ratio	0.403
Roundtrip Efficiency	80 %
Maximum Charge Current	16.7 A
Maximum Discharge Current	24.3 A
Maximum Charge Rate	1 A/Ah

3.7 Converter/Inverter specification and cost data

A converter is a device that converts electric power from direct current (DC) to alternating current (AC) in a process called inversion, and/or from AC to DC in a process called rectification (Lambert et al., 2006). A Solar PV system consist of DC. In Ghana, most electrical appliances operate with AC electricity. The converter/inverter will transform DC power stored by the batteries into AC electricity. For this study, each inverter will have a capacity of 25 kW. The maximum capacity of inverters required is 400 kW, which translates to 8 inverters in total.

3.8 Economic analysis in HOMER

In this study, the major economic output metrics to be regarded for analysis, discussion, feasibility and implementation of the project are NPC and LCOE. NPC of the system takes into account all costs that the system incurs over its lifetime, minus the present value of all the revenue that the system earns over its lifetime. HOMER software calculates the total NPC, C_{NPC} of the project using equation 6 (Lambert et al., 2006)

$$C_{NPC} = \frac{C_{ann,tot}}{CRF\ (i, R_{proj})} \qquad \textbf{(6)}$$

where $C_{ann,tot}$ is the total annualized cost, i the annual real interest rate (the discount rate), R_{proj} the project lifetime, and CRF(i,N) is the capital recovery factor which is given by equation 7 (Lambert et al., 2006)

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \qquad \textbf{(7)}$$

where *i* represents the annual real interest rate and N represents the number of years.

HOMER software uses equation 8 to calculate the levelized cost of energy (LCOE) in $/kWh (Lambert et al., 2006).

$$LCOE = \frac{C_{ann,tot}}{E_{prim} + E_{def} + E_{grid,sales}} \qquad \textbf{(8)}$$

where: $C_{ann, tot}$ is the total annualized cost, E_{prim} and E_{def} are the total amounts of primary and deferrable load, respectively and $E_{grid, sales}$ is the amount of energy sold to the grid per year.

3.9 Sensitivity

Sensitivity Analysis helps to study the systems behaviour under the uncertainty of different parameters of the optimal system. In the sensitivity analysis, the impact of price variability on electricity demand, PV capital cost, diesel price and discount rate on the LCOE and NPC were observed for the optimal systems. The study also conducts a multiple sensitivity analysis of increased electricity demand with increased diesel price and reduced PV cost.

Table 7 lists the sensitivity ranges for various input variables.

Table 7: Parameter ranges for sensitivity analysis of the Optimal System

Input variable	Unit	Sensitivity ranges
Decrease or increase in electricity demand	%	-50, -25, +20, +50, +100
PV capital cost	kW	900, 800, 700, 600
Diesel price	%	+10, +20, +50
Discount rate, from which the model computes the real interest rate	%	7, 10, 16.9[b], 20, 30
Capital subsidy	%	50, 100
Battery costs	%	-5, -10, -15, -20, -25, -30, -40, -45, -50

4.0 RESULTS

4.1 Community energy demand

The electrical load demand was projected from the survey data to the entire community, using the total number of households provided by the community leaders (Chief, Queenmother, Assemblyman, and the Headteacher of the public basic school in the community), which was 589 households. The household load was projected from the survey population of 160 households to the 589 households reported in the community. The survey established average household density in the community to be 9.75, which translates to approximately 536 households, adding justification to the household number provided by the community leaders, hence the decision to go ahead and use it in estimating electrical load demand. As stated in the methodology, the other sectors were entirely covered in the survey. Energy efficiency measures were built into the household demand analysis, ensuring that only LED lighting systems are used in the community.

The total annual electricity demand for Dodi Adjaade Island was estimated at 1,876,410 kWh. Table 11 shows the breakdown of electricity demand by various sectors in the community. The breakdown of electricity demand revealed about 1,764,098 kWh (approximately 94.1%) of the electricity will be consumed by households. Household demand is dominated by television and refrigeration. Most of the households interviewed would want to own more than one television if there is electricity, and this may be justified by the average household size of 9.75. Commercial and light industrial demand follows with 4.3%.

Table 8: Breakdown of annual electricity demand by various sectors

Sector	Electricity Demand (kWh)	Electricity Demand (% of total)
Households	1,764,098	94.01
Commercial	80,778	4.30
Religious bodies	22,206	1.18
Clinic	6,673	0.36
School	2,655	0.14

Average per capita electricity demand is estimated at about 359 kWh per year. This compares with the per capita electricity consumption in Ghana in 2017, which was 417.5 kWh (Energy Commission, 2018). The World Bank's estimated per capita electricity consumption for sub-Saharan Africa for 2014 (the latest data available), excluding the high income countries, is 482.87 (World Bank, 2019b). It must be noted that per the classification of the Ghana Statistical Services (Mensah et al., 2014), Dodi Adjaade would be classified as an urban community, as the population is higher than 5000.

Hourly loads, which were disaggregated for weekdays and weekends, were used in determining the seasonal load for weekdays and weekends, which was then fed into the tool. As detailed earlier in the methodology, factors such as weather conditions and school holidays influenced the estimation of seasonal loads for both weekdays and weekends. Seasonal peak load profile for weekdays is shown in Figure 9. Details of weekday and weekend hourly load profiles for each month of the year are presented in Appendix 12. The peak load for the community is approximately 383 kW. Both the weekday and weekend load profiles for each of the months were fed into HOMER for the modelling.

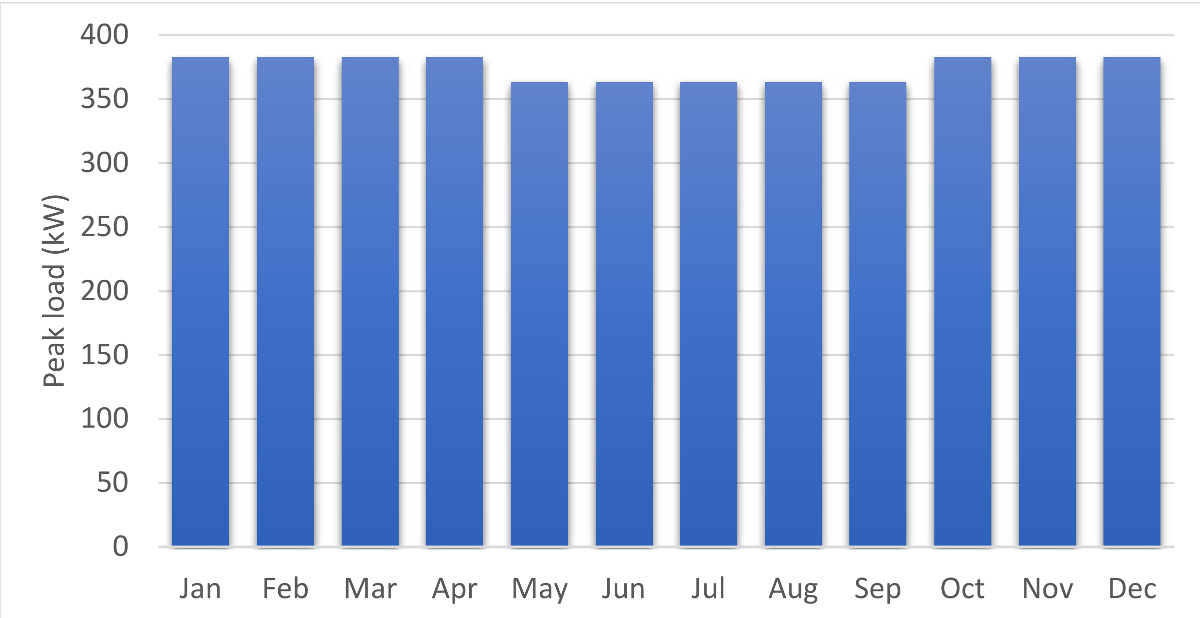

Figure 9: Seasonal peak load profile

4.2 HOMER Pro software optimization results

The economic feasibility of a system depends on parameters such as NPC, LCOE, operating cost, initial cost, fuel cost, renewable fraction, capacity shortage, unmet load, CO_2 emissions, excess electricity, annual electricity production and annual fuel consumption. The HOMER software algorithm searched for the optimum solution among the various sizes considered for the estimated electricity demand. The most feasible solutions were ranked according to the parameters shown above. Five different configurations were considered, as detailed in Table 1Table 9. The best ten selected results from the different configurations are shown in Table 10. Only one result each from configurations C1 and C2 are shown because all the results generated from the model had the same capacity for PV panels and storage batteries in each case.

Table 9: Modelled configurations

Configuration name	Description
Configuration A1	Hybrid of *solar PV*, *storage batteries* and *diesel genset.* Supply the entire estimated load in the community
Configuration A2	Hybrid of *solar PV*, *storage batteries* and *diesel genset*, same combination of systems as in Configuration A, but with electricity available only from 6am to 10pm. For this configuration, power will not be supplied to the community from 10pm to 6am.
Configuration B	Hybrid of *solar PV* and *diesel genset* only Supply the entire estimated load in the community
Configuration C1	Hybrid of *solar PV* and *storage batteries* only Supply the entire estimated load in the community, with no capacity shortage
Configuration C2	Hybrid of *solar PV* and *storage batteries* only Supply load with a 5% capacity shortage constraint in the system, in order to reduce costs. A capacity shortage is a shortfall that occurs between the required operating capacity and the actual amount of operating capacity the system can provide. It was decided to add this configuration due to high costs in **C1**

Table 10: Selected optimization results of feasible hybrid mini-grid system configuration

Conf.	SN	PV Panel (kW)	Genset (kW)	Battery (kWh)	Initial capital ($)	Operating cost ($/yr)	NPC ($)	COE ($)	Ren Frac (%)	Fuel cost ($/yr)	CO_2 (kg/yr)
Configuration A1 (PV/Batt/DG)	1	500	200	2,831	1,291,200	520,415	7,435,627	0.336	29	404,607	944,895
	2	500	200	2,851	1,295,200	520,824	7,444,456	0.336	29	404,476	944,588
	3	500	200	2,694	1,233,800	526,788	7,453,475	0.337	28	414,371	967,697
	4	500	200	2,713	1,237,600	527,222	7,462,400	0.337	28	414,287	967,502
	5	500	200	2,891	1,303,200	521,688	7,462,659	0.337	30	404,254	944,072
	6	500	200	2,733	1,241,600	527,687	7,471,889	0.337	28	414,207	967,314
	7	500	200	2,969	1,318,800	523,361	7,498,012	0.339	30	403,807	943,027
	8	500	200	3,048	1,334,600	524,729	7,529,967	0.340	30	403,052	941,263
	9	500	200	2,891	1,273,200	531,683	7,550,666	0.341	28	413,868	966,522
	10	500	200	3,206	1,366,200	527,534	7,594,678	0.343	30	401,587	937,842
Configuration A2 (PV/Batt/DG, Power available only from 6am to 10pm)	1	400	200	2181	1,140,958	429,864	6,216,274	0.384	29	309,986	723,924
	2	400	200	2206	1,147,953	429,502	6,218,997	0.385	29	309,740	723,348
	3	400	200	2191	1,145,121	429,871	6,220,518	0.385	29	309,979	723,905
	4	400	200	2243	1,157,166	429,008	6,222,366	0.385	29	309,461	722,696
	5	400	200	2295	1,171,116	428,230	6,227,131	0.385	29	309,013	721,650
	6	400	200	2410	1,200,177	425,897	6,228,650	0.385	29	307,579	718,301
	7	400	200	2500	1,220,150	425,543	6,244,447	0.386	29	306,366	715,470
	8	400	200	2174	1,137,494	432,612	6,245,255	0.386	28	312,640	730,121

	9	400	200	2195	1,143,547	432,414	6,248,962	0.386	28	312,522	729,844
	10	400	200	2231	1,152,476	431,858	6,251,333	0.386	28	312,207	729,109
Configuration B (PV/DG)	1	667	460	-	957,967	534,471	7,268,351	0.328	21	454,875	1,063,113
	2	966	460	-	1,237,715	494,597	7,077,318	0.319	27	421,768	985,739
	3	990	460	-	1,261,152	492,637	7,077,612	0.319	27	420,076	981,783
	4	979	460	-	1,250,735	493,584	7,078,375	0.320	27	420,889	983,684
	5	973	460	-	1,244,780	494,198	7,079,674	0.320	27	421,398	984,873
	6	984	460	-	1,256,841	493,199	7,079,931	0.320	27	420,528	982,840
	7	990	460	-	1,262,946	492,700	7,080,146	0.320	27	420,076	981,783
	8	955	460	-	1,226,864	495,773	7,080,347	0.320	27	422,769	988,076
	9	1000	460	-	1,271,569	492,031	7,080,872	0.320	27	419,538	980,525
	10	979	460	-	1,252,529	493,647	7,080,909	0.320	27	420,889	983,684
Conf. C1 (PV/Batt, no capacity shortage)	1	1870	-	30,000	8,034,851	852,597	18,101,280	0.818	100	-	-
Conf. C2 (PV/Batt, 5% capacity shortage)	1	1342	-	23,000	6,106,467	654,213	13,830,620	0.658	100	-	-

Key: DG = Diesel Genset; Batt = Batteries; PV = Solar PV; Conf. = Configuration;

4.3 Simulation results of most optimal and feasible systems

Based on the results presented in Table 10, simulation details of the most optimal results for each configuration, showing the technical and financial data, are presented in Table 11.

Configuration B, which is a hybrid of PV and diesel generator, has the lowest initial cost, NPC and LCOE, but the most expensive operating cost due to amount of diesel required to complement PV in meeting the load demand. This configuration corresponds to an initial capital of $957,967, an operating cost of $534,471/year, a total net present cost of $7,268,350 and a total cost of energy of 0.328 $/kWh. The optimal size of the system for Configuration B is 667 kW PV capacity and 460 kW genset. Notwithstanding the good economic indicators of Configuration B, it has the highest diesel consumption of the five configurations and therefore the lowest renewable fraction of 21.3%.

Configuration A1, which combines all three components of the system, i.e. solar PV, genset and storage batteries, is the second best system among the configurations meeting the full load in the community. The initial cost of $1,291,200 is slightly higher than that of Configuration B. The NPC and LCOE are also slightly higher than Configuration B, but the operating cost is slightly lower, at $520,415, due to the relatively lower diesel consumption. Configuration A1 has a slightly higher renewable fraction of 29.5%, compared to the 21.3% obtained in Configuration B.

Both Configurations C1 and C2 have 100% renewable fraction, though costs are high. The NPC for C1 and C2 are $ 18,101,280 and $ 13,830,620 respectively, compared to $ 7,435,627 for Configuration A1. The LCOE is also high, at $ 0.818 and $ 0.658 respectively, for C1 and C2. LCOE for C1 and C2 are more than twice the LCOE for Configuration A1. As indicated in the component cost analysis in the next section, the high costs are largely driven by high capacity storage batteries. Configuration C1, for example, has battery requirements of 30,000 kWh, with an overall system initial cost of about $ 8 million.

Configuration A2 may be considered if power could be curtailed between 10pm and 6am, when most residents are retiring to bed and businesses have closed operations for the day. Such a system could make a little power available to the clinic for the refrigeration of essential medicine and for emergency cases. Configuration A2 has the lowest NPC and operating costs, though relatively higher initial capital cost and LCOE than Configurations A1 and B. Configuration A2 had almost the same renewable fraction as Configuration A1.

Table 11: Comparative overview of hybrid mini-grid configurations from simulation

Description		Configuration A1 PV/DG/Batt	Configuration A2 PV/DG/Batt	Configuration B PV/DG	Configuration C1 PV/Batt	Configuration C2 PV/Batt
System Sizing	PV capacity (kW)	500	400	667	1870	1342
	Diesel Genset (kW)	200	200	460	-	-
	Battery (kWh)	2,831	2,181	-	30,000	23,000
	Converter (kW)	400	302	383	383	383
Electricity (kWh/yr)	Total electricity production	2,091,634	1,593,775	2,501,455	3,252,450	2,333,141
	PV production	768,661	614,929	1,024,882	3,252,450	2,333,141
	Genset production	1,322,973	978,846	1,476,574	-	-
	AC primary load	1,876,410	1,369,845	1,876,410	1,876,410	1,781,197
	Excess electricity	85,034	82,714	603,147	974,463	172,279
	Unmet Electric load	820	329	0	1,856	95,212
	Capacity shortage	1,824	1,234	0	1,856	95,212
Economics	Net present cost ($)	7,435,627	6,216,274	7,268,350	18,101,280	13,830,620
	Cost of energy ($/kW)	0.336	0.384	0.328	0.818	0.658
	Initial capital cost ($)	1,291,200	1,140,000	957,967	8,030,000	6,110,000
	Operating cost	520,415	429,864	534,471	852,597	654,213
Emissions (kg/yr.)	CO_2	944,895	723,924	1,063,113	-	-
	CO	6,428	4,925	6,701	-	-
	SO_2	2,136	1,774	2,603	-	-

	Unburned hydrocarbons	260	199	292	-	-
	Particular Matter	25.7	19.7	40.6	-	-
	Nitrogen oxides	514	394	6,295	-	-
Fuel consumption	Diesel (L/day)	990	758	1,113	-	-
Battery performance	Energy In (kWh/yr)	436,585	438,243	-	1,527,972	1,447,671
	Energy Out (kWh/yr)	350,529	351,286	-	1,225,057	1,161,753
	Losses (kWh)	87,466	87,730	-	305,911	289,961
	Autonomy (hr)	7.94	8.37	-	84.1	64.5
Inverter performance	Energy In (kWh/yr)	736,058	757,006	437,983	1,973,214	1,874,945
	Energy Out (kWh/yr)	699,255	719,156	416,084	1,874,554	1,781,197
	Losses (kWh/yr)	36,803	37,850	21,899	98,661	93,747
Rectifier performance	Energy In (kWh/yr)	146,638	311,749	-	-	-
	Energy Out (kWh/yr)	139,306	328,157	-	-	-
	Losses (kWh/yr)	7,332	16,408	-	-	-
	PV Panels	4,380	4,380	4,380	4,380	4380

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Hours of operation (hrs/yr)	Diesel Genset	6,636	5,201	6,942	-	-
Number of starts (starts/yr)	Diesel Genset	361	920	380	-	-
Operational life (yr)	Diesel Genset	2.26	2.98	2.16	-	-
Renewable fraction (%)		29.5	29	21.3	100	100

Key: DG = Diesel Genset; Batt = Batteries; PV = Solar PV

4.4 Cost of components

In this section, the cost breakdown of the five Configurations are presented in detail. The total cost of the system includes the capital costs, the replacement and operating costs, and the fuel cost, shown as resource. Figure 10 illustrates the share of each cost component for all five Configuration. All the configurations with genset have diesel cost as the highest cost component, shown as 'resource' in Figure 10. For configurations C1 and C2 which are without genset, capital and replacement costs are the largest contributors to systems cost.

The percentage contributions for each of the components for the three selected configurations are presented in Figure 11 to Figure 13. The three selected configurations represent the PV/Battery/Genset, PV/Genset and PV/Battery. For Configuration A1, which has all three components in the hybrid, battery contributed highest to the capital and replacement costs, at 44% and 77% respectively. Genset contributed the highest share of operating costs, at 45%, followed by battery at 38%. In Configuration B, which had only PV and Genset, PV panels contributes 70% to the capital cost. Genset contributes 85% of operating cost and 93% of replacement costs. For Configuration C1, which represents the systems with only PV and battery, the highest cost for each of the major components is contributed by the battery. Battery cost make up 75%, 87% and 99.64% of the capital, operating and replacement costs respectively. The results are presented in the sensitivity section. Cash flow output for Configurations A1, B and C1 are presented in Appendix 13 to Appendix 15.

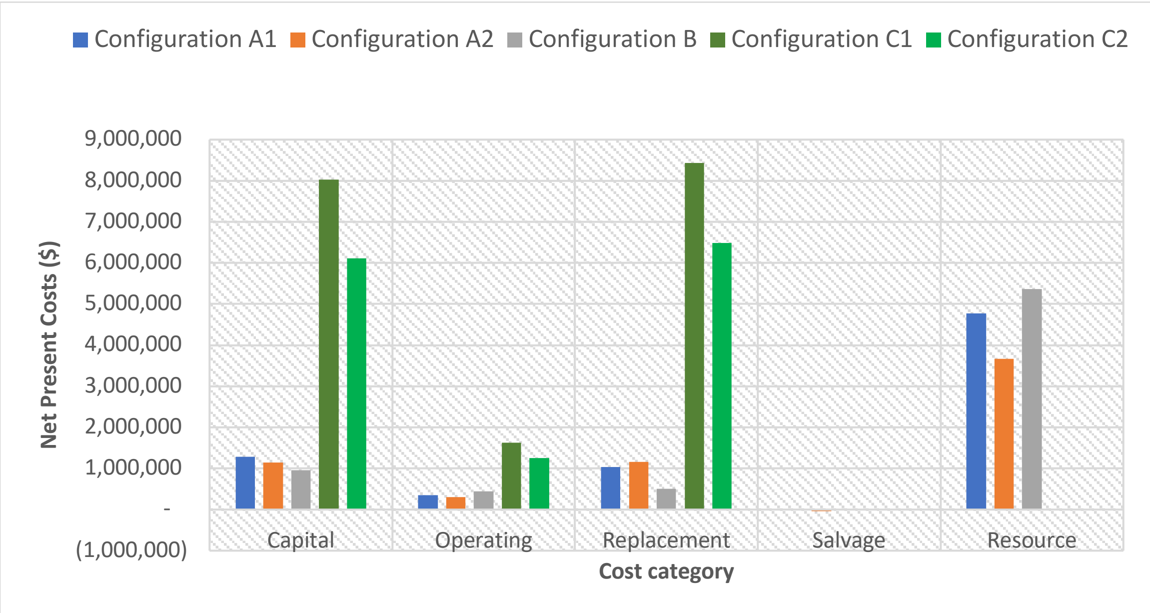

Figure 10: Cost categories for all configurations

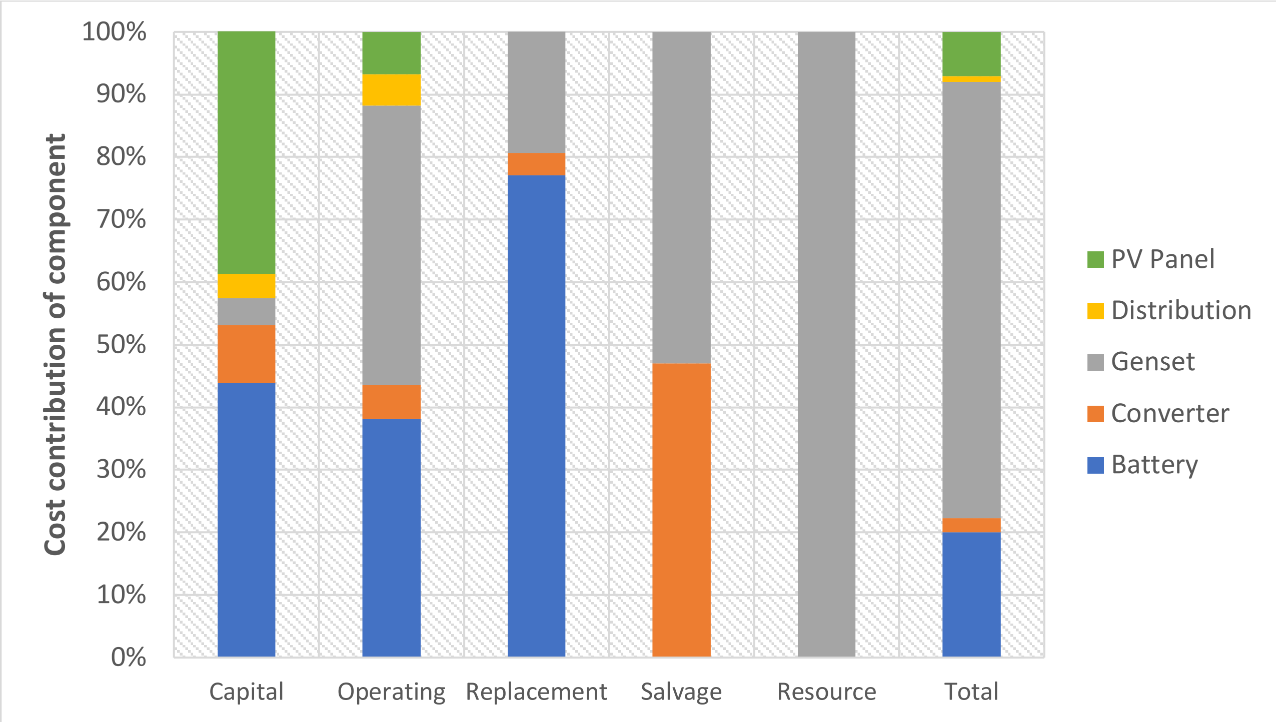

Figure 11: Percentage cost contribution of components for Configuration A1 (PV/Battery/Genset)

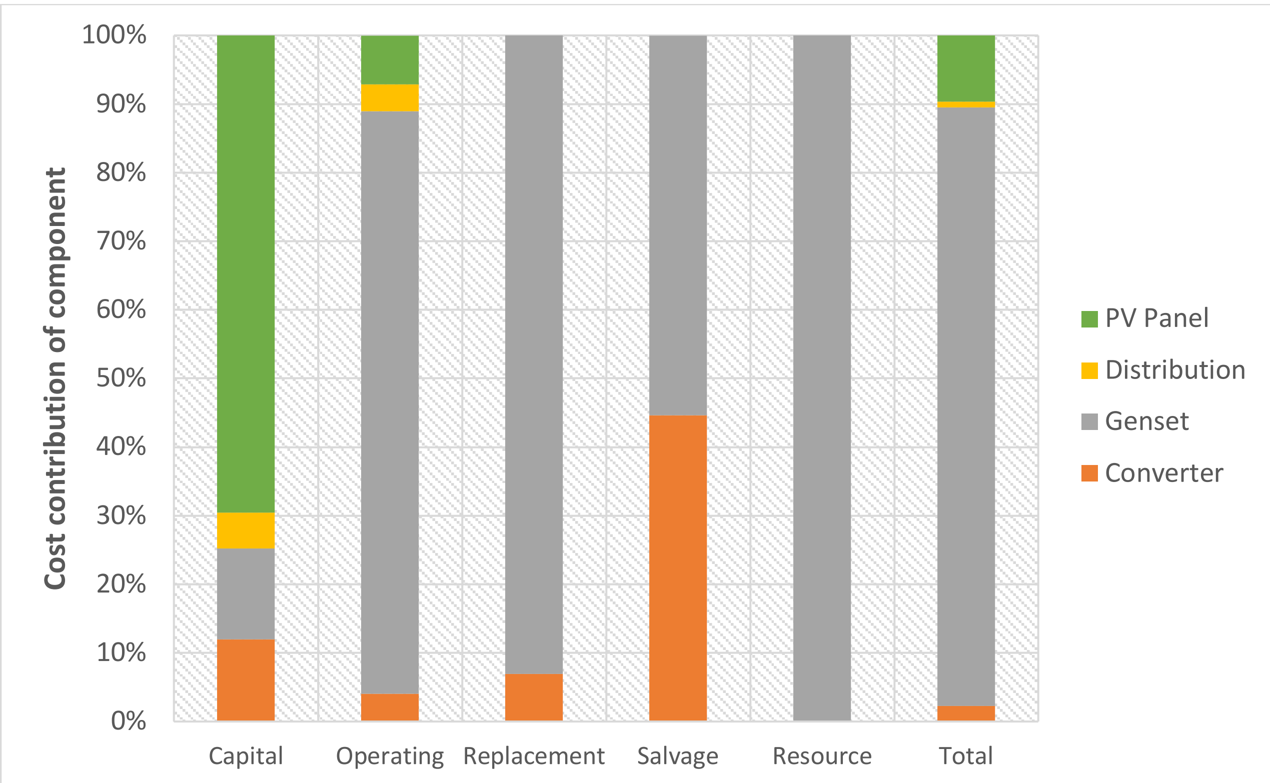

Figure 12: Percentage cost contribution of components for Configuration B (PV/Genset)

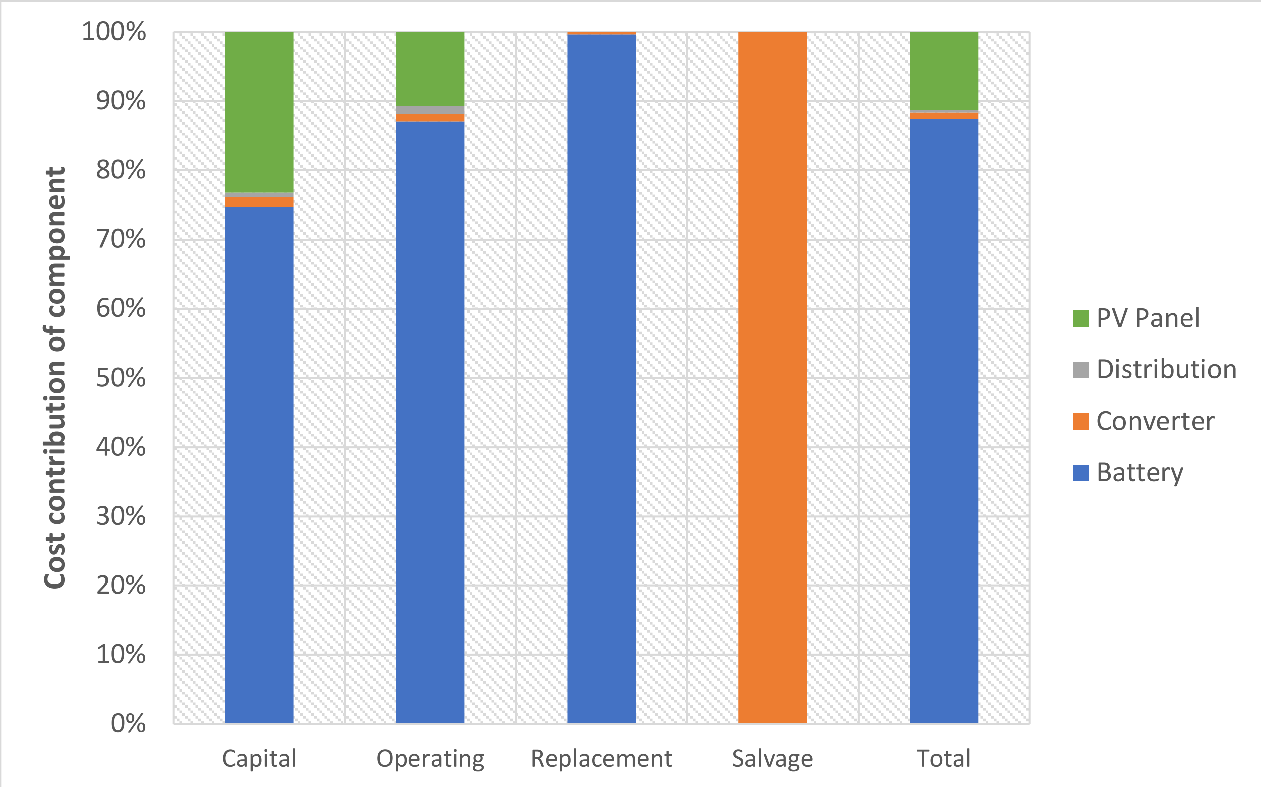

Figure 13: Percentage cost contribution of components for Configuration C1 (PV/Battery)

4.5 Willingness to pay for electricity from mini-grid

Results from the survey indicate the majority of people in the community either use solar or torchlight for lighting. Majority of the solar systems comprise 5 W PV panels and one DC bulb per household, which were donated to them by a politician during election campaign. Households using this solar system do not currently pay anything for power. Those using torchlight pay approximately $0.38 per month on purchase of batteries. The introduction of a mini-grid in the community will require the payment of some tariff for the power, a minimum being the uniform tariff approved by the PURC.

Approximately 90% of the households interviewed were able to state a price they were willing to pay for electricity services from a mini-grid. The remaining 10% would not state any price, saying it would depend on how much electricity they use when the service is available. Figure 1Figure 14 shows the willingness to pay curve constructed using the responses from the interview. As the cost of electricity increases, the percentage of households willing to pay decreases, and vice versa.

Of the respondents who were able to state a price they were willing to pay, only 1% quoted the highest figure of $45 per month, as shown in Figure 14. Approximately 50% of households are willing to pay up to $7.5 per month and 75% willing to pay up to $5 per month. All the households, i.e. 100% of the respondents were willing to pay up to $2.50 per month for electricity.

With regards to commercial customers, respondents were willing to pay from $2 per month (for a grocery store) to $104 per month (in the case of a video centre), with an average of $20 per month. Most of the commercial businesses are willing to pay less than 50% of what they are currently paying to run existing diesel gensets, which averages about $70. The results of this analysis raises concern about the profitability of such a business for the private sector, especially because of the high demand for electricity in the community, coupled with a low willingness to pay higher for the services.

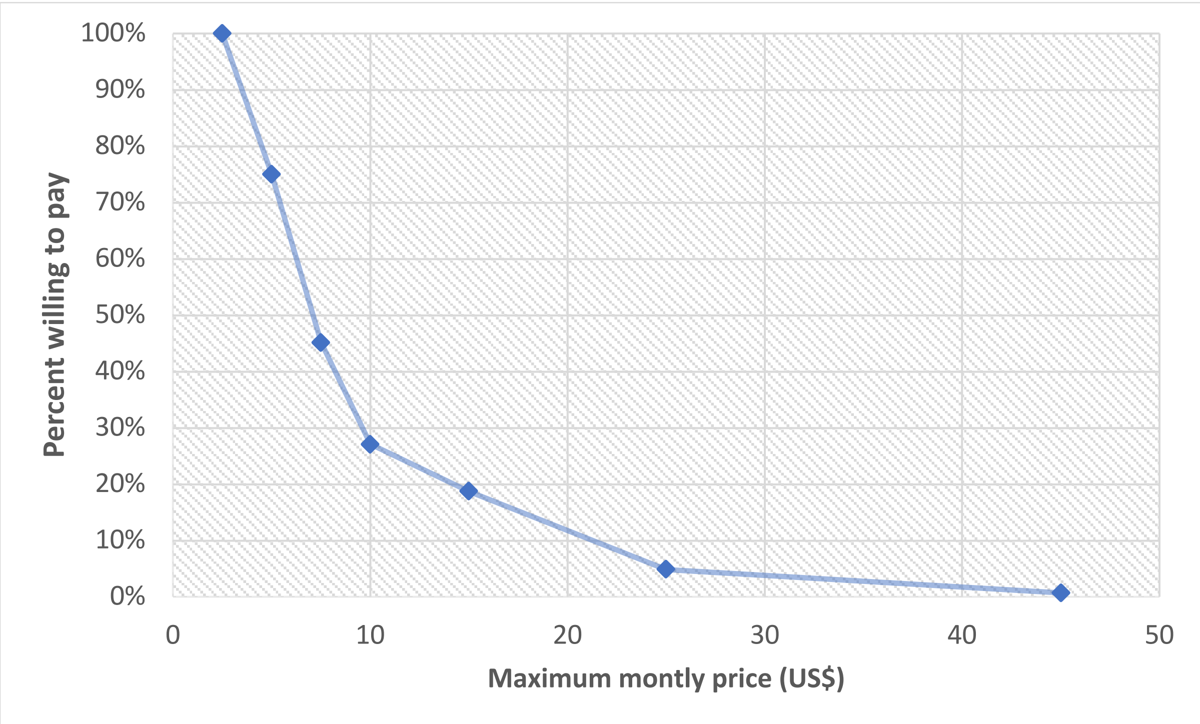

Figure 14: Households willingness to pay for electricity

4.6 Emission analysis

The total CO_2 emissions for Configurations A1, A2, and B are 944,895 kg/year, 723,924 kg/year and 1,063,113 kg/year respectively. No carbon emissions are attributed to Configurations C1 and C2, which do not have any diesel components in the mix. Other emissions, such as carbon monoxide (CO), SO_2, unburnt hydrocarbons particulate matter and nitrogen oxides are summarised in **Error! Reference source not found.**.

Table 12: Emissions from simulated configurations

Emission type	Emission Amount (kg/yr)				
	Conf. A1	Conf. A2	Conf. B	Conf. C1	Conf. C2
CO_2	944,895	723,924	1,063,113	-	-
CO	6,428	4,925	6,701	-	-
SO_2	2,136	1,774	2,603	-	-
Unburned hydrocarbons	260	199	292	-	-
Particular Matter	25.7	19.7	40.6	-	-
Nitrogen oxides	514	394	6,295	-	-

4.7 Sensitivity analysis results

Sensitivity analysis were conducted to study the effect of changes in some of the key variables on the financial parameters. Configuration A1 was used as the base scenario for the sensitivity, as it includes all three components (PV/Battery/Genset) in the hybrid system and is also the configuration with the lowest cost among those with relatively higher renewable fraction.

4.7.1 Sensitivity of electricity demand on NPC and LCOE

The sensitivity of the key financial parameters to the increment of electricity demand has been investigated by decreasing demand in gradual steps up to 50% lower, and increasing gradually up to 100% higher. **Error! Reference source not found.** shows that the NPC reduces for the reduced demand and increases for the increased demand. LCOE increases for reduced demand, increased for 25% and 50% increased demand, but reduces for further increases in demand to 100%. At 50% reduction in electricity demand, NPC reduces by 65%. Conversely, LCOE increases by 29%, from 0.336 $/kWh, to 0.434 $/kWh. At the higher end of demand, NPC increases, as expected, but LCOE does not have a clearly distinct pattern. At 20% increase in electricity demand, the corresponding increase in NPC is 29%, with a 8% increase in LCOE. At 100% increase in electricity demand, NPC increases by a corresponding 114%, while the LCOE increases by 8%.

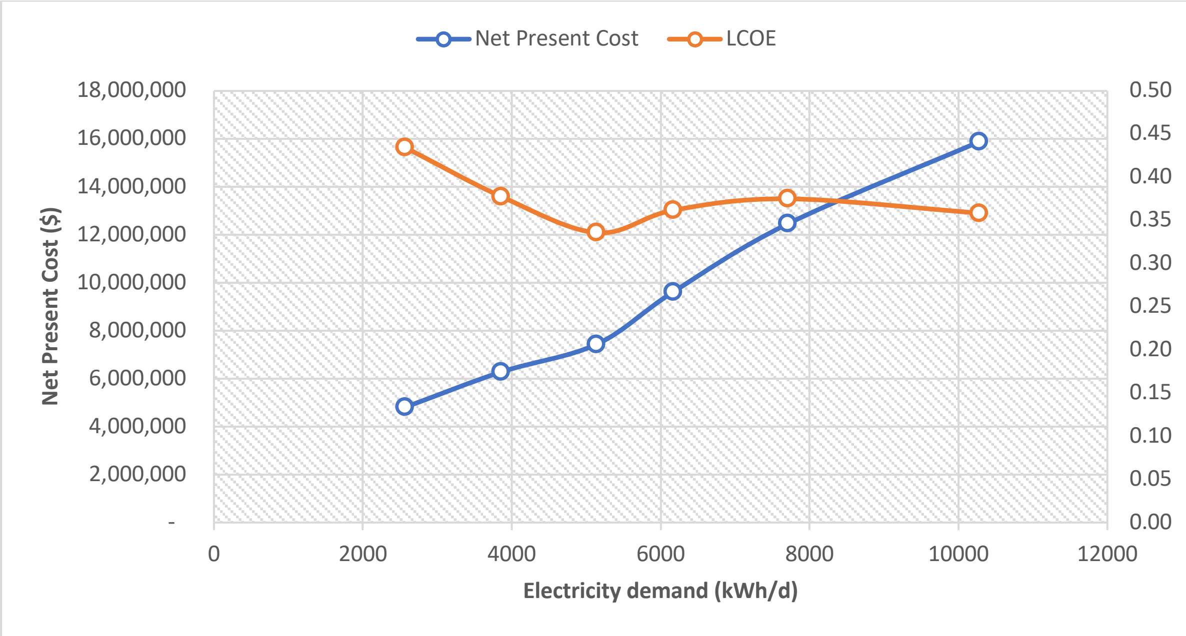

Figure 15: Impact of electricity demand on NPC and LCOE

4.7.2 Sensitivity of diesel price on NPC and LCOE

Historical trends in diesel price suggests that diesel prices in Ghana may not decrease in the foreseeable future. But then again, as Ghana continues to discover crude oil, future prices of diesel may not increase substantially if the economy stays on course. In view of this, the sensitivity analysis considered a 10%, 20% and 50% increase in diesel price, and its consequence on NPC and LCOE. It must be noted here that the price of diesel includes cost of transportation to the island community, which is significant. It has been observed that both NPC and LCOE rise significantly with the increasing price of diesel. The effect of diesel price variation on NPV and LCOE is shown in Figure 16.

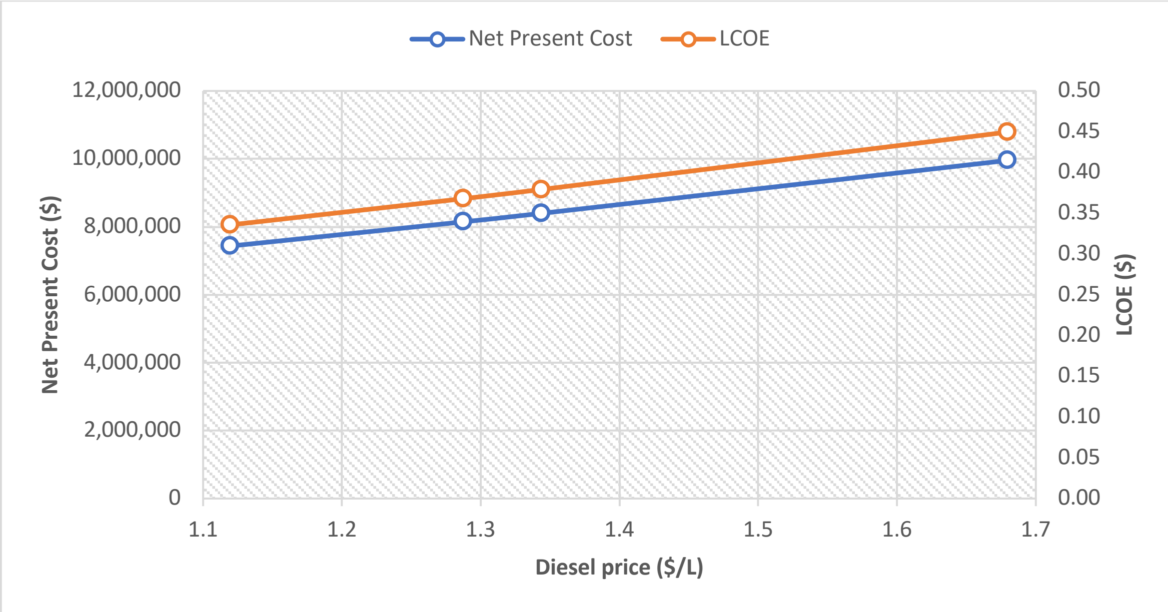

Figure 16: Impact of diesel price variation on NPC and LCOE

4.7.3 Sensitivity of PV panel price on NPC and LCOE

Among the renewable energy technology options and components, the component that has experienced the most reduction in price is PV panels. It is expected that this trend will continue into the foreseeable future, as technology advances. In view of this, this sensitivity looked at PV panel capital and installation costs reducing from the $1000 per kW used in the base scenario. The sensitivity is run using PV panel prices of $900, $800, $700 and $600 per kW of panel capital and installation cost. The consequence of PV panel price variation on NPC and is demonstrated in Fig. 17. Similar to the trend in diesel price sensitivity, it has been observed that both NPC and LCOE reduce with the decreasing price of PV panels.

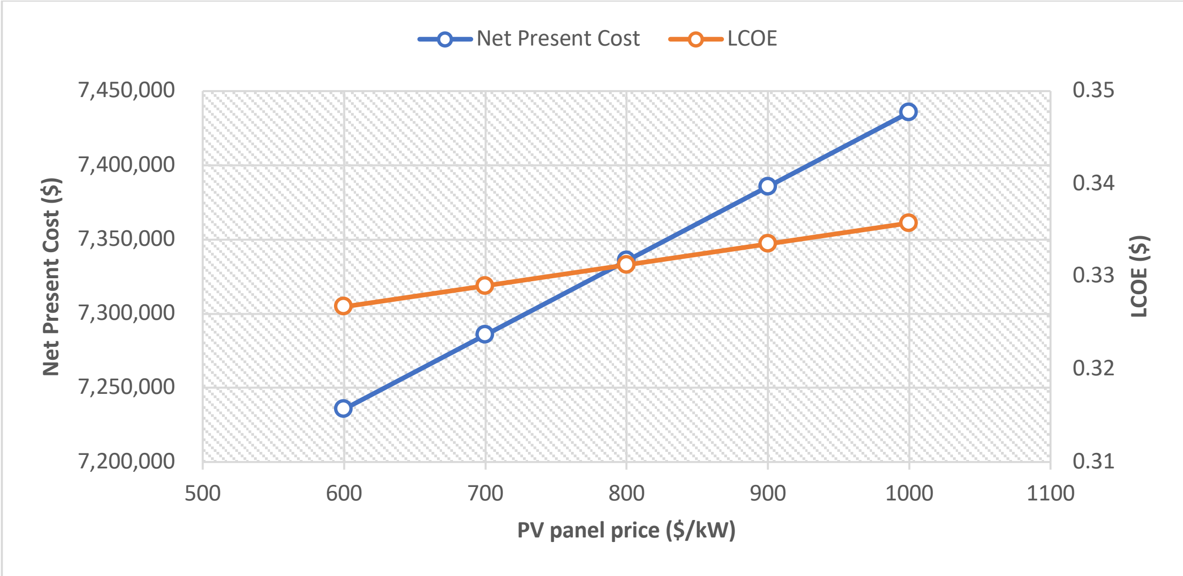

Figure 17: Impact of PV panel price variation on NPC and LCOE

4.7.4 Sensitivity of Discount PV panel price on NPC and LCOE

The discount rate is an important parameter in the financial analysis of investment projects in general. It is used in the discounted cash flow analysis to estimate the value of an investment based on its expected future cash flows. Based on the concept of time value of money, the discounted cash flow analysis helps assess the viability of a project or an investment by calculating the present value of expected future cash flows using a discount rate. The discount rate used in the base case is the interest rate charged to commercial banks and other financial institutions in Ghana for the loans they take from the Bank of Ghana. Lower discount rates may be obtained from international banks. In view of this, lower interest rates of 7% and 10% were run in sensitivity. Also because of uncertainty in the financial system, higher discount rates of 20% and 30% was added to the sensitivity. It should be noted that HOMER computes the real interest rate when the nominal is inputted. The effect of discount rate on NPC and LCOE is portrayed in Fig. 18. NPC reduces with increased discount rate, whereas LCOE increases.

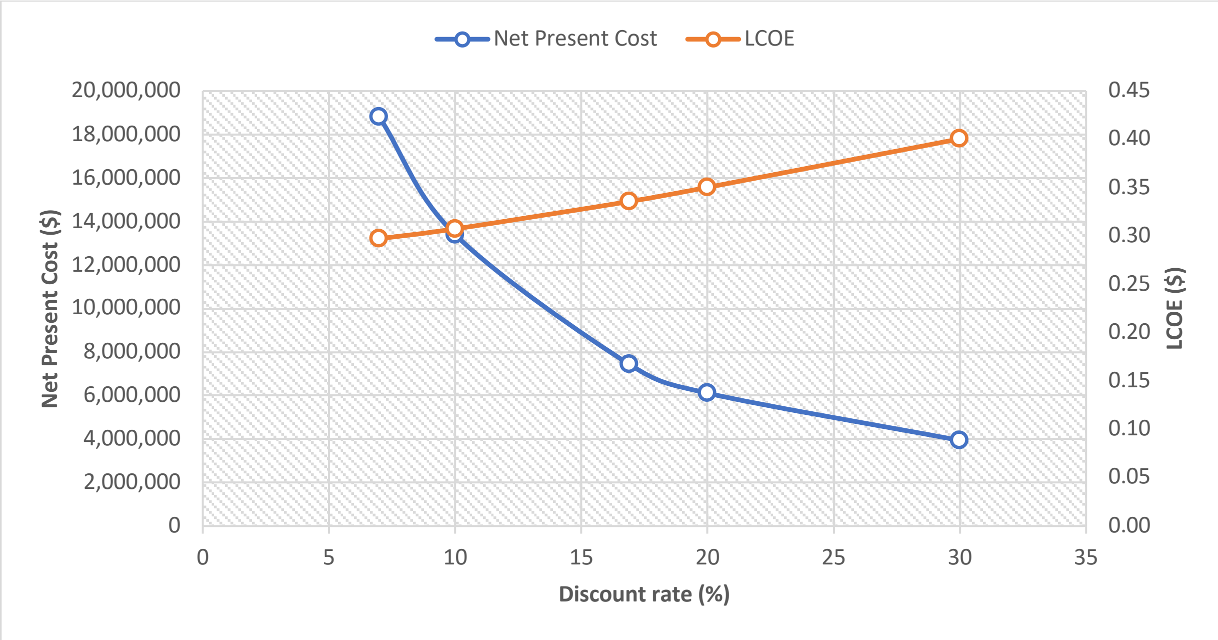

Figure 18: Impact of discount rate variation on NPC and LCOE

4.7.5 Sensitivity of battery cost on NPC and LCOE

Due to the high cost of batteries on the cost of the systems, especially those configurations with solar PV and storage batteries, it was important to explore the cost of batteries on the financial indicators. Figure 19 shows the effect of battery cost on NPC and LCOE for Configuration C1, in gradual reduction steps from 5% to 50% of the base cost. At 50% battery cost reduction, NPC decreases by 37% whereas LCOE decreases by 17%. Access to competitive battery costs could lead to positive effect on overall cost of hybrid mini-grids that include batteries.

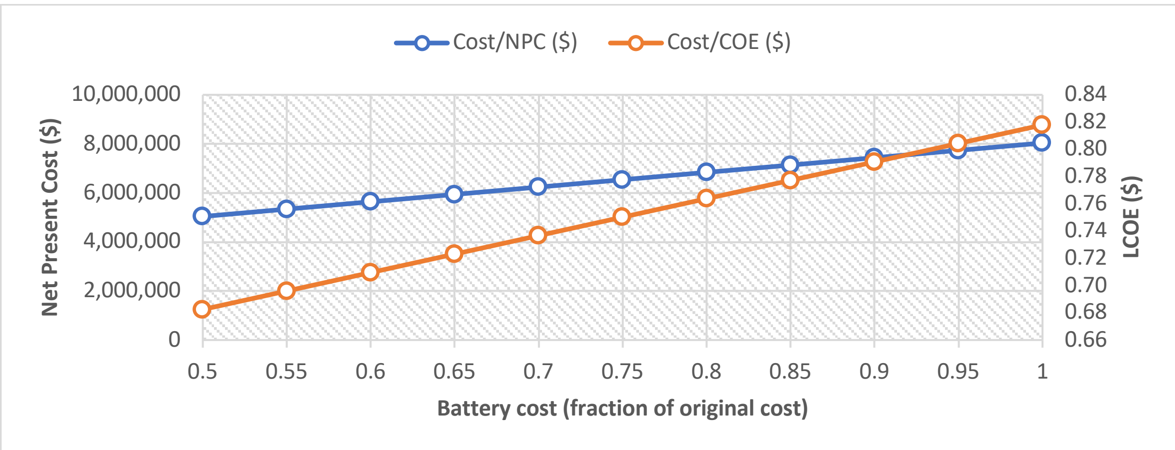

Figure 19: Impact of battery cost on NPC and LCOE

4.7.6 Effect of subsidy on financial indicators

The sensitivity analysis also considered the effect of capital subsidy on the NPC and LCOE. Capital subsidy of 50% and 100% were considered, while operating costs were kept same as in the base scenario. A 50% capital subsidy decreases LCOE by 9% and a 100% capital subsidy decreases LCOE by 18%, as shown in Table 13. There is a similar percentage reduction for NPC. In effect, the bulk of the cost for the mini-grid system appears to come from the operating, replacement and resource costs, rather than the initial capital costs.

Table 13: Effect of subsidy on financial indicators

Capital Subsidy (%)	Initial Capital ($)	Operating cost ($)	LCOE ($/kWh)	NPC ($)
0	1,290,000	520,415	0.336	7,435,627
50	645,000	520,415	0.307	6,790,000
100	0	520,415	0.277	6,144,427

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has presented a systematic evaluation of different hybrid mini-grid configurations for Dodi Adjaade, an island community in the Kwahu Afram Plains North District. A model of the hybrid system was developed in HOMER software to perform a complete parametric analysis on the system configurations and to select the most convenient one from economic perspectives, using time tested financial indicators: initial costs, operating costs, net present cost (NPC) and cost of energy (LCOE). Five configurations were modelled from different combinations of solar PV, storage batteries and diesel genset.

The lowest LCOE obtained among the configurations considered is 0.328 $/kWh (or 1.574 GHC/kWh). This is much higher than the existing March 2018 electricity tariff published by the Public Utilities Regulatory Commission (PURC) of 0.2768 GHC/kWh (more than 500% higher) charged to lifeline customers, and 0.5555 GHC/kWh (about 280% higher) charged to most residential customers in the 51-300 kWh/month (second tier) consumption bracket. As a matter of fact, the LCOE is 96% higher than the 0.8010 GHC/kWh charged to residential consumers in the highest tier, whose demand exceeds 600 kWh/month. The cost of energy is however comparable to costs obtained in similar studies deploying similar configurations in several countries across the globe, a few of which were summarised earlier in Table 2. The sensitivity analysis shows that even at 100% capital subsidy, the LCOE is approximately 0.277 $/kWh or 1.330 GHC/kWh, still higher compared to current tariffs. Only the highest bracket non-residential tariffs of 113.8 GHC/kWh for consumers in the 601+ kWh bracket comes close to the LCOE from the 100% capital subsidy system.

It is clear from the results that tariffs would be higher than the current uniform tariffs approved by the PURC for residential customers. Meanwhile, households in the community are willing to use a plethora of appliances but the willingness to pay analysis indicates that only 50% of the residents are willing to pay only up to $7.5 per month for electricity, roughly translating to less than 30 kWh of electricity per month. With the Government of Ghana’s policy that tariffs across the country must be uniform, this is not a viable investment opportunity for the private sector.

5.2 Recommendations

Presently, the Government of Ghana has adopted the public sector (or utility-based) model for mini-grids operation in Ghana. Under this model, the utility is responsible for all mini-grid operations in the country. The utility operates the mini-grids in much the same way that it operates the national electricity network.

Power is generated by the utility, fed into the community distribution grid and supplied to the consumers, at the same rates paid by the utility's customers connected to its main grid.

The cost comparison with the existing tariff structure in Ghana shows that there is the need for a significant subsidy on the tariff paid by mini-grid customers if the Government of Ghana's Uniform Tariff Structure remains unchanged. Capital cost subsidy alone may still not be a viable option for the private sector under the current uniform tariff policy. The analysis in this study has shown that apart from capital costs, replacement and O&M costs are also high, to the extent that even at 100% capital subsidy, unit cost of energy is still higher than current uniform tariffs charged by the distribution utilities. This finding is consistent with findings from the government pilot mini-grids, where the developers are of the opinion that uniform tariffs charged to customers are not enough to meet replacement and O&M costs[2].

Global experience indicates that both public and private mini-grid business models have advantages and disadvantages, and exploring avenues towards implementing them side by side may not be a bad option for Ghana. While public models are more likely to receive finance and deliver a uniform tariff to consumers as the case is in Ghana, communities who aren't immediately included in the rural electrification plan are at risk of being left behind. Also, utilities are known to have market-driven priorities, and running remote, low-revenue mini-grids in rural areas of developing countries is not a high priority area for many utilities. Meanwhile private models can reduce the burden on utilities and give them more time to focus on improving the national grid, yet private developers often can't access government subsidies, thereby struggling to make projects bankable. For private developers, tariffs also need to deliver profits, so it is essential to engage with communities before setting a price plan, if the policy allows it. The private sector model has been implemented in a number of countries in Africa, including Kenya, Tanzania and Nigeria. In Nigeria for instance, private developers negotiate tariffs with communities and operate independently of the national Nigerian Rural Electrification Authority (REA), though the REA expect to provide subsidies to the operators (Nigeria Rural Electrification Agency, 2017). An analysis by the REA has found that mini-grids in Nigeria have unit cost of energy in the region of 0.33 $/kWh to 0.51 $/kWh, though they found these mini-grids to have provided considerable savings on existing energy costs in the beneficiary communities (Nigeria Rural Electrification Agency, 2017). In view of this, the mini-grid policy/regulation in Nigeria allows mini-grids with capacities less than 1 MW to operate under a tariff flexibility with the freedom to charge cost reflective tariffs, in order to speed up the mini-grid electrification process. For mini-grids to be viable to the private sector, the Ghana government could in addition to integrating them into national electrification plans, set up a coherent enabling environment and learn from other countries to see what works.

[2] Personal Interview with TTA, Barcelona

Getting the right investment arrangement for private sector participation in mini-grids in Ghana depends on getting the right policies and regulations in place. In essence, the Government of Ghana is central to making mini-grids work well in the country. A focus on private sector participation would require a lowering of operating risks faced by investors to help ensure a sufficient return, and this would happen if tariffs are dispassionately reviewed and made favourable to the private sector, or that there is a capital subsidy scheme that takes care of the shortfalls arising from the uniform tariff structure. As the case is in other countries, mini-grids can be a viable option in Ghana, but a clear legislation/regulation is needed regarding what cost-reflective tariffs the private sector can charge. Without this clarity, there is unlikely to be significant interest from investors.

Clearly, there is the need for a special mini-grid tariff or a cross-subsidisation scheme. A previous study by SNV in 2017[3] estimated that if total installed mini-grid peak loads in the country were to reach 50 MW, compared to a total 5000 MW national electricity capacity installation in 2030, the mini-grid plants would be contributing just 0.1% of the total. This is not expected to increase national uniform tariffs substantially. A greater challenge however, is how these subsidy scheme could be implemented in a way that payments due private sector operators are done in a timely fashion. It is critical that the Government of Ghana explores private sector co-participation in the development of mini-grids using these option. This would, however, require that some compensation from the cross-subsidy scheme is paid to the private operators to enable them to recover their investments. Without a compensation package to private sector participants, they cannot charge uniform tariffs and remain in business, as the lifeline tariffs will not be able to sustain the operations cost of private sector mini-grids.

[3] SNV (2017). Analysis of policies and regulatory frameworks governing the deployment of off-grid based mini-grid electrification systems in Ghana.

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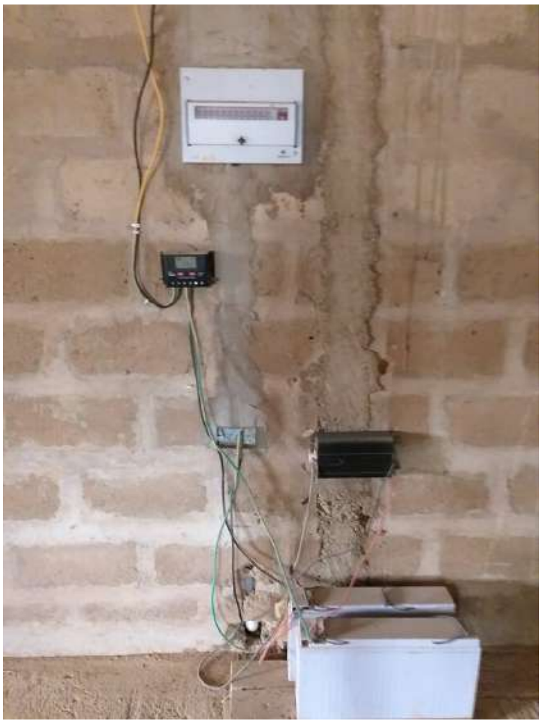
7.0 APPENDICES

Appendix 1

Other photos taken from the community

Community survey process

Inverter in one of the households

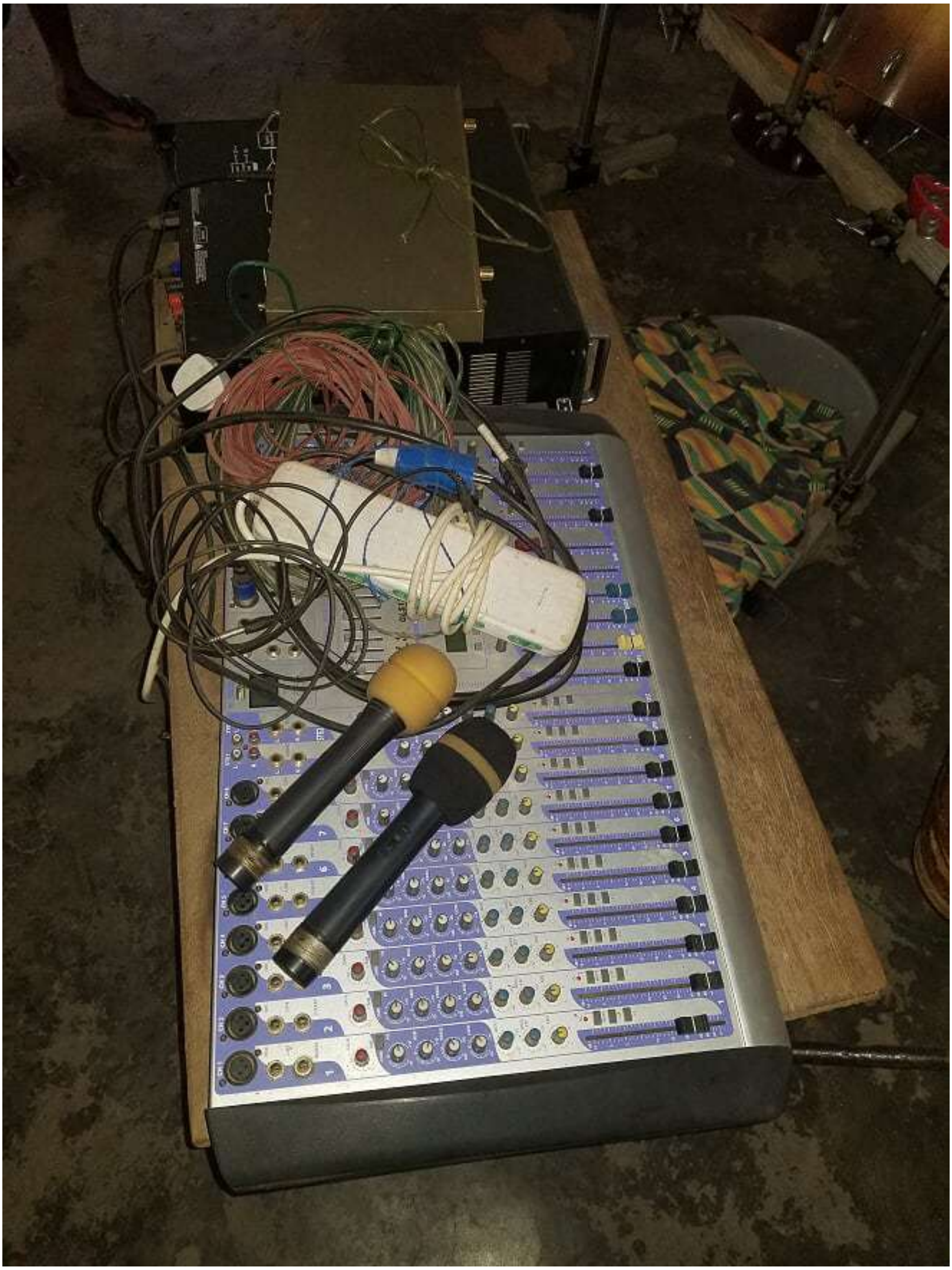


Solar systems connection in one of the households

Genset used by some segments of the community

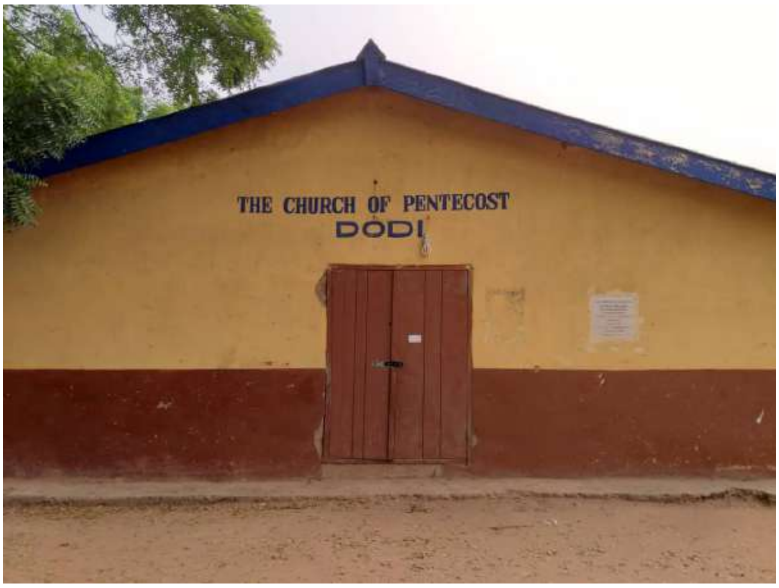
Community health post

One of the schools in the community with a solar panel that was used previously



Electricity powered musical instruments at one of the local churches

Diesel powered grinding mills in the community



A religious building in the community

Appendix 2

Households Load Estimation Questionnaire

Viability Analysis of Mini-Grid Based Electrification in Ghana

Questionnaire for Households in **Dodi Adjaade**

December 2018 – January 2019

Questionnaire number: ________________ Name of suburb: ________________________

GPS coordinate of house: ____

The Netherlands Development Organisation (SNV) under the Voice for Change Partnership (V4CP) Programme is studying the viability of solar, wind, battery and diesel hybrid mini-grids for electrification in Ghana. Mini-grids are isolated grids that provide electricity of similar quality to the grid (explain the concept of mini-grids in detail to respondent). The information provided will be very useful and help accelerate this study. We WILL NOT share your information with any person or agency without your consent.

PART 1: GENERAL INFORMATION

Date:	Start time:	Name of interviewer:
Interviewee's name:		Interviewee's age:
Contact No.:		Educational background:
Occupation:		

Question	**Response (circle or enter)**
Gender of respondent	1. Male 2. Female
Languages spoken (select all the apply)	1. Ewe 2. Ga-Adangbe 3. Akan 4. Hausa

	5. Others (indicate ________________)
Religious affiliation	1.Christian 2. Islam 3. Traditionalist 4. other
What is your marital status?	1. Married/Cohabiting 2. Single/Never married 3. Divorced/separated 4. Widow/Widower
What relationship do you have with the head of household?	1. Wife 2. Son 3. Daughter 4. Other relative 5. Self
How many people live in this household permanently?	Enter number:
What is the highest level of education attained by the head of household?	1. None 2. Primary 3. Secondary 4. Trade school 5. University 6. Other (specify):
What is this household's main source of income?	
What is the second most important income source?	
What is the third most important income source?	
How much do you earn in a month? Could be computed from a daily or annual income stream of entire household, where necessary **(if exact figure is available, you should write it)**	1. GHC 0 – 100 2. GHC 100 – 200 3. GHC 200 – 300 5. GHC 300 – 400 5. GHC 400 – 500 6. GHC 500 and above
What is your current source of power? (list all sources)	
How much do you pay for your current source of power?	
Are you willing to pay more for electricity from mini-grids?	
What is the maximum you are willing to pay for electricity from mini-grids?	

Would it be acceptable to you if electricity is only available from the evening until early morning, or you will only accept a 24h availability?	
Do the people pay for any community service? If yes, kindly indicate the type of service and amount paid	
Does the community contribute in case someone fails to pay?	
Do you have any knowledge of electricity?	

PART 2: Residential/Household/Domestic Load Estimation

Which of the following appliance(s) is/are available in this house? If none, which appliance(s) do you want to own in the future when the community is electrified?

Household load appliances and their electricity consumption hours			
Appliance	Quantity	Time of Use (h/d)	Rated Power (W)
Radio			
Mobile phone			
TV (LCD/LED)			
TV (CRT)			
Bulbs (LED)			
Bulbs (CFL)			
Bulbs (Incandescent)			
Refrigerator			
Deep freezer			
DVD player			
Fan (Standing)			
Fan (Ceiling)			
Laptop computer			
Desktop computer			
Electric iron			
Others (specify below)			

Appendix 3

Commercial/Light Industrial Loads Estimation Questionnaire

Viability Analysis of Mini-Grid Based Electrification in Ghana

Questionnaire for Commercial/Light Industrial Loads in **Dodi Adjaade**

December 2018 – January 2019

Questionnaire number: ____________________ Name of suburb: _______________________

GPS coordinate of Business: ____

The Netherlands Development Organisation (SNV) under the Voice for Change Partnership (V4CP) Programme is studying the viability of solar, wind, battery and diesel hybrid mini-grids for electrification in Ghana. Mini-grids are isolated grids that provide electricity of similar quality to the grid (explain the concept of mini-grids in detail to respondent). The information provided will be very useful and help accelerate this study. We WILL NOT share your information with any person or agency without your consent.

PART 1: GENERAL INFORMATION

Date:	Start time:	Name of interviewer:
Interviewee's name:		Interviewee's age:
Contact No.:		Educational background:
Is the business your main occupation (state the business)?		
If the business is not your main occupation, kindly state your main occupation:		

Question	Response (circle or enter)

What is your current source of power? (list all sources)	
How much do you pay for your current source of power? State if daily, weekly or monthly	
Are you willing to pay more for electricity from mini-grids?	
What is the maximum you are willing to pay for electricity from mini-grids?	
For your business, would it be acceptable to you if electricity is only available during a certain time of day (**respondent should state time of day**), or you will only accept a 24h availability?	

PART 2: Commercial/light industrial load estimation

This section will be used to estimate the commercial and light industrial loads in the community

Commercial loads appliances and their electricity consumption hours				
Service	Appliance	Quantity	Time of Use (h/d)	Rated Power (W)
Flour Mill (mainly for grinding cereals and cassava)	Grinding machine			
	Bulbs (LED)			
	Bulb (CFL)			
	Bulb (Incandescent)			
	Small Radio			
Cold store	Refrigerator			
	Freezer			
	Electronic Scale			
	Bulbs (LED)			
	Bulb (CFL)			
	Bulb (Incandescent)			

Water Pump				
Small business (Type of business)				

Appendix 4

Schools Load Estimation Questionnaire

Viability Analysis of Mini-Grid Based Electrification in Ghana

Questionnaire for Schools in **Dodi Adjaade**

December 2018 – January 2019

Questionnaire number: ___________________ Name of suburb: ______________________

GPS coordinate of School: ____

The Netherlands Development Organisation (SNV) under the Voice for Change Partnership (V4CP) Programme is studying the viability of solar, wind, battery and diesel hybrid mini-grids for electrification in Ghana. Mini-grids are isolated grids that provide electricity of similar quality to the grid (explain the concept of mini-grids in detail to respondent). The information provided will be very useful and help accelerate this study. We WILL NOT share your information with any person or agency without your consent.

PART 1: GENERAL INFORMATION

Date:	Start time:	Name of interviewer:
Name of school:		Name of respondent:
Position of respondent:		Contact No.:

Question	**Response (circle or enter)**
What is your current source of power? (list all sources)	
How much do you pay for your current source of power?	

PART 2: School Load Estimation

School loads appliances and their electricity consumption hours				
School	Appliance	Quantity	Time of Use (h/d)	Power (W)
Nursery Level	Bulbs (LED)			
	Bulb (CFL)			

	Bulb (Incandescent)			
	Desktop computer			
	Laptop			
Primary Level	Bulbs (LED)			
	Bulb (CFL)			
	Bulb (Incandescent)			
	Desktop computer			
	Laptop			
	Printer			
	Photocopier			
Junior High Level	Bulbs (LED)			
	Bulb (CFL)			
	Bulb (Incandescent)			
	Desktop computer			
	Laptop			
	Printer			
	Photocopier			

Appendix 5

Clinics Load Estimation Questionnaire

Viability Analysis of Mini-Grid Based Electrification in Ghana

Questionnaire for Clinic in **Dodi Adjaade**

December 2018 – January 2019

Questionnaire number: _________________ Name of Suburb: _________________________

GPS coordinate of Clinic: ____

The Netherlands Development Organisation (SNV) under the Voice for Change Partnership (V4CP) Programme is studying the viability of solar, wind, battery and diesel hybrid mini-grids for electrification in Ghana. Mini-grids are isolated grids that provide electricity of similar quality to the grid (explain the concept of mini-grids in detail to respondent). The information provided will be very useful and help accelerate this study. We WILL NOT share your information with any person or agency without your consent.

PART 1: GENERAL INFORMATION

Date:	Start time:	Name of interviewer:
Name of Clinic:		Name of respondent:
Position of respondent:		Contact No.:

Question	**Response (circle or enter)**
What is your current source of power? (list all sources)	
How much do you pay for your current source of power?	

PART 2: Hospital/Clinic Load Estimation

Hospital/Clinic loads and their electricity consumption hours				
	Appliance	Quantity	Time of Use (h/d)	Power (W)
Hospital/Clinic	Bulbs (LED)			
	Bulb (CFL)			
	Bulb (Incandescent)			
	Vaccine refrigerator			
	Microscope			
	Radio			
	TV (LED)			
	TV (CRT)			

Appendix 6

Religious Buildings Load Estimation Questionnaire

Viability Analysis of Mini-Grid Based Electrification in Ghana

Questionnaire for Religious Building Managers in **Dodi Adjaade**

December 2018 – January 2019

Questionnaire number: ________________ Name of suburb: _______________________

Religion type (underline): Christianity / Islam / Traditional

GPS coordinate of Building: ____

The Netherlands Development Organisation (SNV) under the Voice for Change Partnership (V4CP) Programme is studying the viability of solar, wind, battery and diesel hybrid mini-grids for electrification in Ghana. Mini-grids are isolated grids that provide electricity of similar quality to the grid (explain the concept of mini-grids in detail to respondent). The information provided will be very useful and help accelerate this study. We WILL NOT share your information with any person or agency without your consent.

PART 1: GENERAL INFORMATION

Date:	Start time:	Name of interviewer:
Name of religious body (e.g. Pentecost church):		Respondent's name:
Respondent's contact No.:		Position of respondent (e.g. Imam):

Question	Response (circle or enter)
What is your current source of power? (list all sources)	
How much do you pay for your current source of power?	
Are you willing to pay more for electricity from mini-grids?	
Would it be acceptable to you if electricity is only available during a certain time of day (**respondent should state time of day**), or you will only accept a 24h availability?	

PART 2: Religious Building Load Estimation

Religious building appliances and their electricity consumption hours				
Appliance	Quantit y	Time of Use (h/d)	Days in the week when used	Power (W)
Bulbs (LED)				
Bulb (CFL)				
Bulb (Incandescent)				
Desktop computer				

Appendix 7

Summary of household electrical appliances

Dodi Households	Appliance	Quantity	Power Rating (W)	Time of Use	Usage (hr/d)	AC loads (kWh/d)
151 Households	Radio	47	7	12:00-18:00	6	1.974
	Radio	77	7	06:00-18:00	12	6.468
	Radio	140	7	00:00-23:00	24	23.52
	Mobile Phone	282	7	04:00-07:00	2	3.948
	Mobile Phone	282	7	21:00-00:00	3	5.922
	TV-LCD/LED	79	80	08:00-12:00	4	25.28
	TV-LCD/LED	79	80	18:00-22:00	4	25.28
	TV-CRT	30.5	120	08:00-12:00	4	14.64
	TV-CRT	30.5	120	18:00-22:00	4	14.64
	Internal Bulbs-LED	245	11	18:00-23:00	5	13.475
	External Bulbs-LED	151	15	18:00-23:00	5	11.325
	External Bulbs-LED	302	15	18:00-06:00	12	54.36
	Refrigerator	30	200	06:00-18:00	12	72
	Refrigerator	70	200	00:00-23:00	24	336
	Deep freezer	38	300	00:00-23:00	24	273.6
	DVD player	20	30	08:00-12:00	4	2.4
	DVD player	50	30	18:00-22:00	4	6
	Fan-Standing	195	50	18:00-23:00	5	48.75
	Fan-Ceiling	131	40	18:00-23:00	5	26.2
	Laptop computer	65	40	18:00-23:00	5	13

	Desktop computer	6	120	18:00-22:00	4	2.88
	Electric iron	42	1000	06:00-07:00	1	42
	Electric iron	42	1000	12:00-13:00	1	42
	Electric iron	43	1000	17:00-18:00	1	43

Appendix 8

Summary of school electrical appliances

Name of School	Category	Appliances	Quantity	Power Rating (W)	Time of Use	Usage (hr/d)	AC loads (kWh/d)
Dodi Adjade K. G & Primary School	Nursery School (4 Classrooms)	Classroom Bulbs-LED	4	11	05:00-06:00	1	0.044
		External Bulb-LED	1	15	18:00-06:00	12	0.18
		Ceiling Fan	2	40	12:00-15:00	3	0.24
	Primary School (6 Classrooms)	Classroom Bulbs-LED	6	11	05:00-06:00	1	0.066
		External Bulbs-LED	2	15	18:00-06:00	12	0.36
	HeadMaster Office	Office Bulbs-LED	1	11	06:00-08:00	2	0.022
		Desktop Computer	4	120	09:00-11:00	2	0.96
					13:00-15:00	2	0.96
		Laptop Computer	1	50	09:00-12:00	3	0.15
		Printer	1	100	08:00-09:00	1	0.1
					15:00-16:00	1	0.1
		Photocopier	1	200	08:00-09:00	1	0.2
					15:00-16:00	1	0.2
		Celing Fan	1	40	12:00-15:00	3	0.12

Bright Spark International School	Nursery School (4 Classrooms)	Classroom Bulbs-LED	4	11	05:00-06:00	1	0.044
		External Bulbs-LED	1	15	18:00-06:00	12	0.18
		Ceiling Fan	1	40	12:00-15:00	3	0.12
	Primary School (6 Classrooms)	Classroom Bulbs-LED	6	11	05:00-06:00	1	0.066
		External Bulbs-LED	2	15	18:00-06:00	12	0.36
	HeadMaster Office	Office Bulbs-LED	1	11	06:00-08:00	2	0.022
		Desktop Computer	4	120	09:00-11:00	2	0.96
					13:00-15:00	2	0.96
		Laptop Computer	1	40	09:00-12:00	2	0.08
		Printer	1	100	08:00-09:00	1	0.1
					15:00-16:00	1	0.1
		Photocopier	1	200	08:00-09:00	1	0.2
					15:00-16:00	1	0.2
		Ceiling Fan	1	40	12:00-15:00	3	0.12

Appendix 9

Summary of commercial/light industrial electrical appliances

Type of Business	Appliances	Quantity	Power Rating (W)	Time of Use	Usage (hr/d)	AC loads (kWh/d)
Glocery Store	Radio	1	7	06:00-22:00	16	0.112
	Deep Freezer	1	200	00:00-23:00	24	4.8
	Internal Bulbs-LED	1	11	06:00-08:00	2	0.022
				18:00-22:00	4	0.044
	External Bulbs-LED	1	15	18:00-06:00	12	0.18
Flour Mill	Grinding Machine	1	3000	07:00-11:00	4	12
				18:00-19:00	1	3
	Internal Bulbs-LED	1	11	06:00-07:00	1	0.011
	External Bulbs-LED	1	15	18:00-19:00	1	0.015
	Radio	1	7	07:00-11:00	4	0.028
Mini Bar	Radio	1	7	06:00-18:00	12	0.084
	Refrigerator	1	150	00:00-23:00	24	3.6
	Internal Bulbs-LED	2	11	18:00-00:00	6	0.132
	External Bulbs-LED	2	15	18:00-00:00	6	0.18
Glocery Store	Internal Bulbs-LED	2	11	06:00-08:00	2	0.044
	External Bulbs-LED	2	15	18:00-21:00	3	0.09
Flour Mill	Grinding Machine	2	3000	07:00-11:00	4	24
				18:00-19:00	1	6
	Internal Bulbs-LED	1	11	18:00-19:00	1	0.011
	External Bulbs-LED	1	15	18:00-19:00	1	0.015
	Radio	1	7	07:00-11:00	4	0.028

Flour Mill	Grinding Machine	2	3000	07:00-11:00	4	24
				18:00-19:00	1	6
	Internal Bulbs-LED	1	11	18:00-19:00	1	0.011
	External Bulbs-LED	1	15	18:00-19:00	1	0.015
	Radio	1	7	07:00-11:00	4	0.028
Fashion Shop	Sewing Machine	1	100	07:00-12:00	5	0.5
				13:00-18:00	5	0.5
	Electric Iron	1	1000	08:00-10:00	2	2
				13:00-15:00	2	2
	Ceiling Fan	1	40	10:00-12:00	2	0.08
				13:00-17:00	4	0.16
Mini Bar/Information Center	Radio	1	7	06:00-18:00	12	0.084
	Deep Freezer	1	200	00:00-23:00	24	4.8
	Interrnal Bulbs-LED	2	11	18:00-23:00	6	0.132
	External Bulbs-LED	1	15	18:00-06:00	12	0.18
	Ceiling Fan	2	40	18:00-23:00	6	0.48
	Amplifier	1	1000	05:00-06:00	1	1
				12:00-13:00	1	1
				18:00-19:00	1	1
	Microphone Decoder	1	40	05:00-06:00	1	0.04
				12:00-13:00	1	0.04
				18:00-19:00	1	0.04
Small Pharmacy Shop	Radio	1	7	06:00-22:00	16	0.112
	Refrigerator	1	150	06:00-18:00	12	1.8

	Internal Bulbs-LED	1	11	18:00-22:00	4	0.044
	External Bulbs-LED	1	15	18:00-22:00	4	0.06
	Standing Fan	1	50	12:00-16:00	4	0.2
	Ceiling Fan	1	40	12:00-16:00	4	0.16
Video Centre	Bulbs-LED	4	11	18:00-00:00	6	0.264
	Ceiling Fan	2	40	12:00-00:00	12	0.96
	Amplifier	2	500	12:00-00:00	12	12
	Decoder	4	15	12:00-22:00	10	0.6
	TV-LED	3	80	12:00-00:00	12	2.88

Appendix 10

Summary of clinic load electrical appliances load

Category	Appliance	Quantity	Power Rating (W)	Time of Use	Usage (hr/d)	AC loads (kWh/d)
Wards (4 rooms)	Internal Bulbs-LED	8	11	18:00-00:00	6	0.528
	Ceiling fan	8	40	12:00-16:00	4	1.28
				20:00-23:00	3	0.96
	TV-LED	2	80	06:00-22:00	16	2.56
	Radio	2	7	06:00-18:00	12	0.168
Consultation Room/Office	Vaccine refrigerator	2	160	00:00-23:00	24	7.68
	Microscope	1	18	08:00-09:00	1	0.018
				20:00-21:00	1	0.018
	Ceiling fan	2	40	12:00-16:00	4	0.32
	Laptop	1	60	08:00-12:00	4	0.24
	Internal Bulbs-LED	1	11	18:00-00:00	6	0.066
	Radio	1	7	06:00-18:00	12	0.084
Waiting Room	TV-LED	2	60	06:00-22:00	16	1.92
	Ceiling fan	4	40	08:00-23:00	15	2.4
	Internal Bulbs-LED	2	11	18:00-00:00	6	0.132
Building	External Bulbs-LED	4	15	18:00-06:00	12	0.72

Appendix 11

Summary of religious buildings electrical appliances

Name of Religious Body	Appliances	Quantity	Power Rating (W)	Time of Use	Usage (hr/d)	AC loads (kWh/d)
Pentecost Church	Internal Bulbs-LED	8	11	07:00-10:00	3	0.264
				18:00-20:00	2	0.176
	External Bulbs-LED	3	15	18:00-21:00	3	0.135
	Ceiling Fan	7	40	07:00-10:00	3	0.84
				18:00-20:00	2	0.56
	Laptop Computer	1	60	07:00-10:00	3	0.18
				18:00-20:00	2	0.12
	Microphone system	2	8	07:00-10:00	3	0.048
				18:00-20:00	2	0.032
	Amplifier	1	1000	07:00-10:00	3	3
				18:00-20:00	2	2
	Mixer	1	800	07:00-10:00	3	2.4
				18:00-20:00	2	1.6
	Projector	1	100	07:00-10:00	3	0.3
				18:00-20:00	2	0.2
	Combo	3	150	07:00-10:00	3	1.35
				18:00-20:00	2	0.9
Global Evangelical Church	Internal Bulbs-LED	4	11	07:00-10:00	3	0.132
				18:00-20:00	2	0.088
	External Bulbs-LED	2	15	18:00-21:00	3	0.09

	Ceiling Fan	4	40	07:00-10:00	3	0.48
				18:00-20:00	2	0.32
	Microphone system	2	8	07:00-10:00	3	0.048
				18:00-20:00	2	0.032
	Amplifier	1	1000	07:00-10:00	3	3
				18:00-20:00	2	2
	Mixer	1	800	07:00-10:00	3	2.4
				18:00-20:00	2	1.6
	Combo	2	150	07:00-10:00	3	0.9
				18:00-20:00	2	0.6
The Great Commission Church	Internal Bulbs-LED	6	11	07:00-10:00	3	0.198
				18:00-20:00	2	0.132
	External Bulbs-LED	2	15	18:00-21:00	3	0.09
	Ceiling Fan	4	40	07:00-10:00	3	0.48
				18:00-20:00	2	0.32
	Microphone system	2	8	07:00-10:00	3	0.048
				18:00-20:00	2	0.032
	Amplifier	1	1000	07:00-10:00	3	3
				18:00-20:00	2	3
	Mixer	1	800	07:00-10:00	3	2.4
				18:00-20:00	2	1.6
	Combo	1	150	07:00-10:00	3	0.45
				18:00-20:00	2	0.3
Divine Healing Chur	Internal Bulbs-LED	6	11	07:00-10:00	3	0.198

				18:00-20:00	2	0.132
	External Bulbs-LED	2	15	18:00-21:00	3	0.09
	Ceiling Fan	3	40	07:00-10:00	3	0.36
		3	40	18:00-20:00	2	0.24
	Microphone system	2	8	07:00-10:00	3	0.048
		2	8	18:00-20:00	2	0.032
	Amplifier	1	1000	07:00-10:00	3	3
		1	1000	18:00-20:00	2	2
	Mixer	1	800	07:00-10:00	3	2.4
		1	800	18:00-20:00	2	1.6
	Combo	1	150	07:00-10:00	3	0.45
		1	150	18:00-20:00	2	0.3
Bethel Prayer Ministry	Internal Bulbs-LED	6	11	07:00-10:00	3	0.198
		6	11	18:00-20:00	2	0.132
	External Bulbs-LED	2	15	18:00-21:00	3	0.09
	Ceiling Fan	4	40	07:00-10:00	3	0.48
		4	40	18:00-20:00	2	0.32
	Microphone system	2	8	07:00-10:00	3	0.048
		2	8	18:00-20:00	2	0.032
	Amplifier	1	1000	07:00-10:00	3	3
		1	1000	18:00-20:00	2	2
	Mixer	1	800	07:00-10:00	3	2.4
		1	800	18:00-20:00	2	1.6
	Combo	1	150	07:00-10:00	3	0.45

		1	150	18:00-20:00	2	0.3
Mosque	Internal Bulbs-LED	2	11	04:00-06:00	2	0.044
		2	11	18:00-22:00	4	0.088
	External Bulb-LED	1	15	18:00-06:00	12	0.18
	Microphone system	1	8	04:00-06:00	2	0.016
		1	8	12:00-19:00	7	0.056
	Amplifier	1	500	04:00-06:00	2	1
		1	500	12:00-19:00	7	3.5
Voodu Glikpo Shrine	Internal Bulbs-LED	1	11	18:00-20:00	2	0.022
	External Bulb-LED	1	15	18:00-06:00	12	0.18
Kpakpa Klidi Shrine	Internal Bulbs-LED	1	11	18:00-20:00	2	0.022
	External Bulb-LED	1	15	18:00-06:00	12	0.18

Appendix 12

Weekday Seasonal Load Profile (kW)

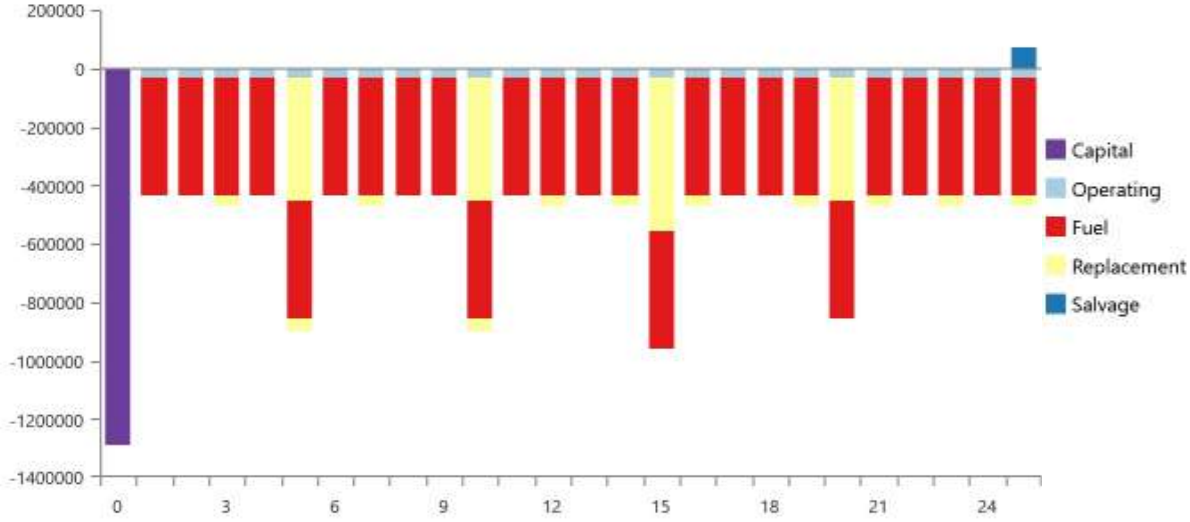
Hour of day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9
1	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9
2	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9
3	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9
4	165.4	165.4	165.4	165.4	165.4	165.4	165.4	165.4	165.4	165.4	165.4	165.4
5	166.6	166.6	166.6	166.6	166.6	166.6	166.6	166.6	166.6	166.6	166.6	166.6
6	165.1	165.1	165.1	165.1	165.1	165.1	165.1	165.1	165.1	165.1	165.1	165.1
7	174.8	183.2	183.2	172.4	179.6	183.2	180.2	164.6	177.8	183.2	183.2	177.2
8	170.1	184.8	184.8	165.9	178.5	184.8	179.6	152.3	175.4	184.8	184.8	174.3
9	237.4	252.1	252.1	233.2	245.8	252.1	246.9	219.6	242.7	252.1	252.1	241.6
10	249.9	251.1	251.1	249.5	250.6	251.1	250.7	248.3	250.3	251.1	251.1	250.2
11	229.4	232.2	232.2	228.6	231.0	232.2	231.2	226.0	230.4	232.2	232.2	230.2
12	218.7	234.9	234.9	214.1	228.0	234.9	229.1	199.0	224.5	234.9	234.9	223.3
13	96.6	112.8	112.8	92.0	105.9	112.8	107.0	76.9	102.4	112.8	112.8	101.2
14	104.4	112.8	112.8	102.0	109.2	112.8	109.8	94.2	107.4	112.8	112.8	106.8
15	111.3	111.3	111.3	111.3	111.3	111.3	111.3	111.3	111.3	111.3	111.3	111.3
16	110.2	110.2	110.2	110.2	110.2	110.2	110.2	110.2	110.2	110.2	110.2	110.2
17	363.3	363.3	363.3	363.3	363.3	363.3	363.3	363.3	363.3	363.3	363.3	363.3
18	382.6	382.6	382.6	382.6	355.8	355.8	355.8	355.8	355.8	382.6	382.6	382.6
19	363.3	363.3	363.3	363.3	356.1	356.1	356.1	356.1	356.1	363.3	363.3	363.3
20	363.7	363.7	363.7	363.7	356.4	356.4	356.4	356.4	356.4	363.7	363.7	363.7
21	363.6	363.6	363.6	363.6	356.4	356.4	356.4	356.4	356.4	363.6	363.6	363.6
22	300.1	300.1	300.1	300.1	292.8	292.8	292.8	292.8	292.8	300.1	300.1	300.1
23	166.6	166.6	166.6	166.6	159.2	159.2	159.2	159.2	159.2	166.6	166.6	166.6

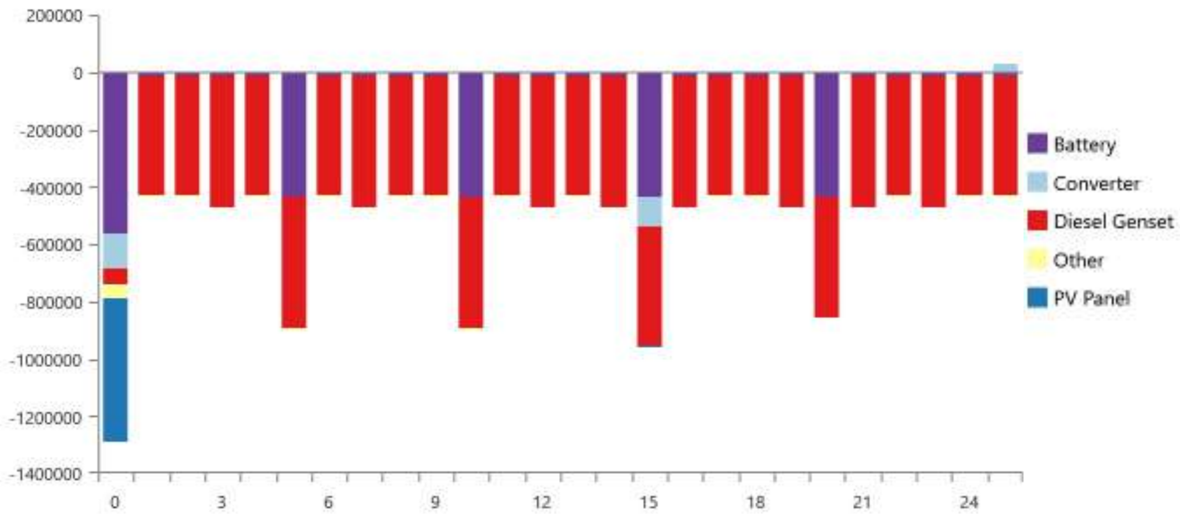
Weekend Seasonal Load Profile (kW)

Hour of day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
0	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9
1	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9
2	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9
3	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9	156.9
4	165.4	165.4	165.4	165.4	165.4	165.4	165.4	165.4	165.4	165.4	165.4
5	166.6	166.6	166.6	166.6	166.6	166.6	166.6	166.6	166.6	166.6	166.6
6	165.1	165.1	165.1	165.1	165.1	165.1	165.1	165.1	165.1	165.1	165.1
7	195.1	195.1	195.1	195.1	195.1	195.1	195.1	195.1	195.1	195.1	195.1
8	196.1	196.1	196.1	196.1	196.1	196.1	196.1	196.1	196.1	196.1	196.1
9	262.9	262.9	262.9	262.9	262.9	262.9	262.9	262.9	262.9	262.9	262.9
10	250.1	250.1	250.1	250.1	250.1	250.1	250.1	250.1	250.1	250.1	250.1
11	232.1	232.1	232.1	232.1	232.1	232.1	232.1	232.1	232.1	232.1	232.1
12	234.7	234.7	234.7	234.7	234.7	234.7	234.7	234.7	234.7	234.7	234.7
13	111.7	111.7	111.7	111.7	111.7	111.7	111.7	111.7	111.7	111.7	111.7
14	111.7	111.7	111.7	111.7	111.7	111.7	111.7	111.7	111.7	111.7	111.7
15	110.7	110.7	110.7	110.7	110.7	110.7	110.7	110.7	110.7	110.7	110.7
16	110.2	110.2	110.2	110.2	110.2	110.2	110.2	110.2	110.2	110.2	110.2
17	363.3	363.3	363.3	363.3	363.3	363.3	363.3	363.3	363.3	363.3	363.3
18	382.6	382.6	382.6	382.6	355.8	355.8	355.8	355.8	355.8	382.6	382.6
19	363.3	363.3	363.3	363.3	356.1	356.1	356.1	356.1	356.1	363.3	363.3
20	363.7	363.7	363.7	363.7	356.4	356.4	356.4	356.4	356.4	363.7	363.7
21	363.6	363.6	363.6	363.6	356.4	356.4	356.4	356.4	356.4	363.6	363.6
22	300.1	300.1	300.1	300.1	292.8	292.8	292.8	292.8	292.8	300.1	300.1
23	166.6	166.6	166.6	166.6	159.2	159.2	159.2	159.2	159.2	166.6	166.6

Appendix 13

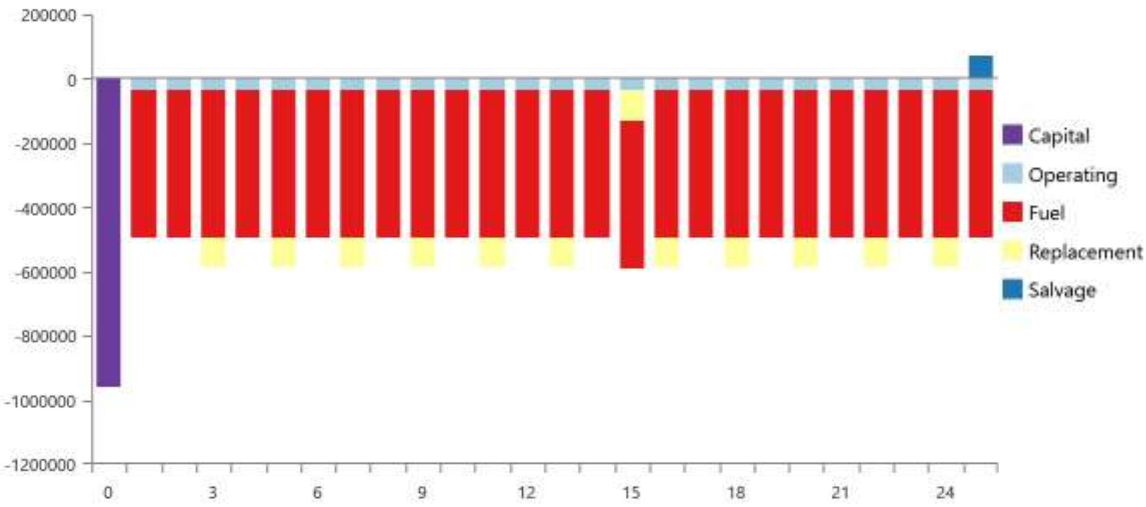
Cash flow of Configuration A1 (PV/Battery/Genset)

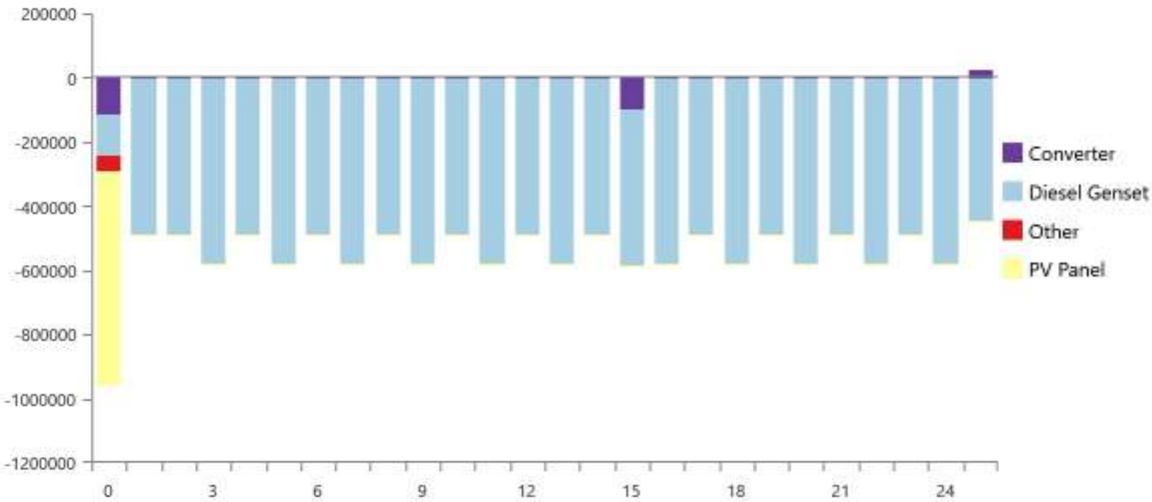




Appendix 14

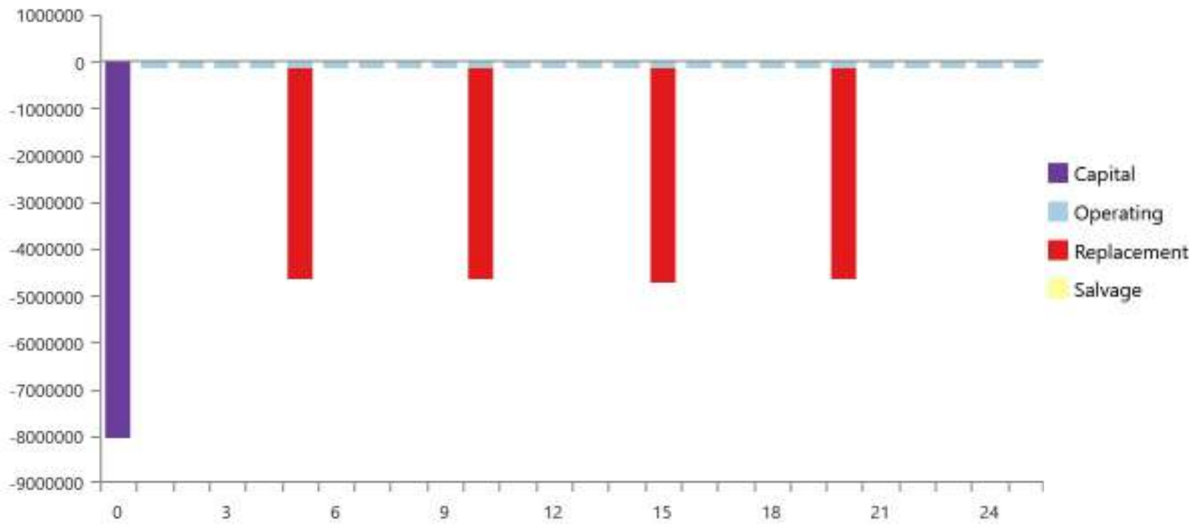
Cash flow of Configuration B (PV/Genset)

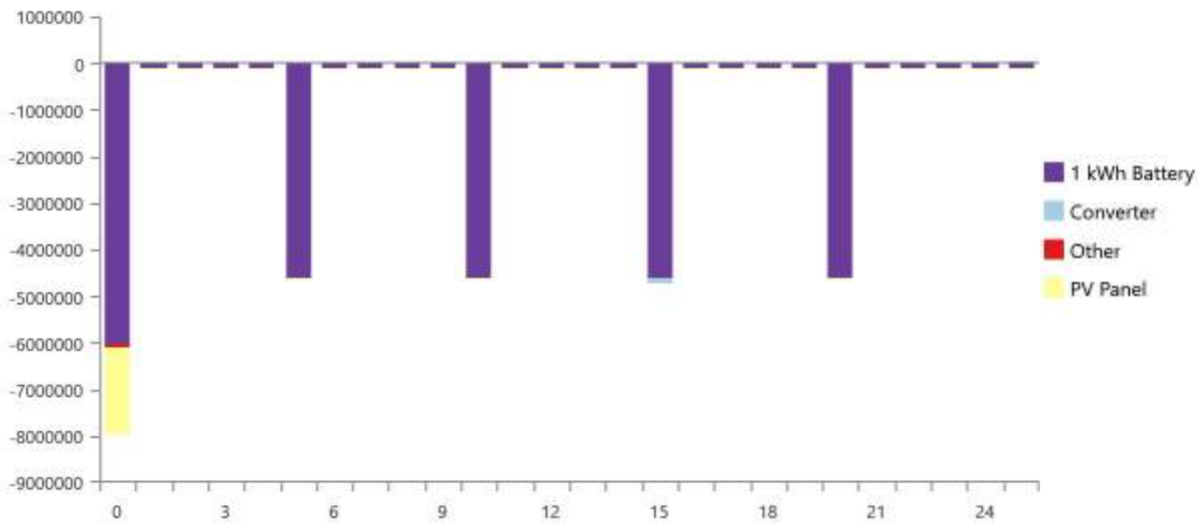




Appendix 15

Cash flow of Configuration C1 (PV/Battery)





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