TECHNO-ECONOMIC ANALYSIS OF SOLAR HOME SYSTEM (SHS) IN CAMBODIA

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ABSTRACT

Providing rural areas with a feasible electrification system has always been a mind-blowing issue for the policy makers in different countries. A well-established electrification system can bring about numerous advantages for the people living in these areas. Improving the condition of life, health and education as well as the public growth are among these benefits. Cambodia, with a population of 15 million, is one of those countries with a significant potential of renewable energies yet with insufficient amount of exploitation. Solar energy as one of the most available and cheapest sources of energy can be properly utilized in Cambodia to make up for an amount of this deficiency in sustainable energy harvesting. In this study, the feasibility of using Solar Home System (SHS) for a rural area in Cambodia with no access to electricity is investigated both from economical and technical aspects. Three cases of electricity loads was specified and closely analysed for this purpose. These cases included low (9W for 8h) , average (36 W for 3 h) and high (63 W for 4 h). For these cases, 40Wp, 55Wp and 2×65Wp PV options were found to be suitable resulted from technical analysis. From economical analysis, annualized life cycle cost (ALCC) was also determined theoretically. The three cases showed 74.46, 102.38, 241.99 (kWh) values for ALCC. Besides, the levelised unit cost of electricity (LUCE) was calculated to be 1.13, 0.71 and 0.99 (US$./kWh) for the mentioned case studies. Comparing the analytical results with HOMER simulation, nearly 90% agreement was reached between the two methods. Finally, after comparing each proposed case with grid extension option, the most feasible choice for the purpose of electrification of this special area was recognized.

ABSTRAK

Menyediakan kawasan luar bandar dengan kebolehan pelaksanaan sistem bekalan elektrik telah sentiasa menjadi isu pemikiran untuk pembuat kebijakan diberbagai negara. Suatu sistem elektrifikasi yang mantap boleh membawa banyak kemanfaatan terhadap orang-orang yang hidup dikawasan tersebut. Perbaikan kondisi kehidupan, kesihatan dan pendidikan serta pertumbuhan awam merupakan manfaat yang diperoleh. Kemboja, dengan jumlah penduduk sebanyak 15 juta jiwa, adalah salah satu negara yang memiliki potensi perbaharuan tanaga yang cukup besar dengan jumlah eksploitasi yang masih rendah. Tenaga solar merupakan salah satu sumber tenaga yang paling memungkinkan dan murah untuk dikembangkan secara potensial di Kamboja untuk meningkatkan kekurangan penuaian tenaga mampan. Dalam kajian ini, disiasati kemungkinan penggunaan Sistem Home Suria (SHS) bagi kawasan luar bandar di Kemboja dengan tiada akses kepada bekalan elektrik dari aspek ekonomi dan teknikal. Tiga kes beban elektrik telah ditentukan dan rapat dianalisis untuk tujuan ini. Kes-kes ini digolongkan rendah (9W +8 jam), purata (36 W selama 3 jam) dan tinggi (63 W selama 4 jam). Bagi kes ini, 40Wp, 55Wp dan 2 × PV 65Wp pilihan telah didapati sesuai hasil daripada analisis teknikal. Daripada analisis ekonomi, kos kehidupan kitaran tahunan (ALCC) juga telah ditentukan secara teori. Ketiga-tiga kes menunjukkan 74,46, 102,38, 241,99 (kWh) nilai bagi ALCC. Selain itu, kos unit levelised elektrik (LUCE) telah dikira sebagai 1.13, 0,71 dan 0,99 (US$./KWh) untuk kajian kes yang disebut. Membandingkan keputusan analisis dengan simulasi Homer, hampir 90% didapati telah dicapai di antara kedua-dua kaedah. Akhirnya, selepas membandingkan setiap kes yang dicadangkan dengan pilihan lanjutan grid, pilihan yang paling sesuai untuk tujuan elektrifikasi kawasan khas ini telah diiktiraf.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Symbols and Abbreviations

Abbreviation & Symbols

ALCC annualized life cycle cost

BOS balance of solar home system

C_0 Total capital cost of all component

C_m miscellaneous cost

CRF capital recovery factors

CUF The capacity utilization factor

D daily load

DOD Determine depth of discharge

$E^{AC}_{T,day}$ Total AC energy required per day (AC Wh/day)

EAC electricity of Cambodia

h Hours of operation per day (h/day)

Isc short circuit current

i discount rate

L load

$LUCE_{SHS}$ levelied unit cost of electricity from an SHS

MEF ministry of economic and finance

MIME ministry of industries, mines and energy

MPPT maximum power point tracker

N households

N PV system lifetime

NPV Net Present Value

n lifetime of each component

η_{batt} Efficiency of battery

$\eta_{inverter}$ Efficiency of inverter

η_{cc} Efficiency of charge controllers

$\eta_{mismatch}$ Efficiency of mis-match factor

η_{temp} Efficiency of temperature

η_{dust} Efficiency of Dust derating

O&M Operation and maintenance

P_r^{AC} Total AC power required (Watt AC)

$P_{r,CFL}^{AC}$ AC power required per CFL (Watt AC)

$P_{generated}$ power generated (Wh)

PV Photovoltaic

PWM Pulse width modulation

RGC Royal Government of Cambodia

REF Rural electrification fund

SHS Solar home systems

SPV Standalone photovoltaic

sunhr Sunshine hours

V volt

v number of battery replacements

WB World Bank

x inflation rate

CHAPTER ONE: INTRODUCTION

1.1 Introduction

Electrification sometimes have been based on its results in financial growth, however it's usually recognized that power is a crucial but an inadequate catalyst for this matter. Furthermore, approach to electricity considered for the essential condition of modernization. It is constantly on the indicate success and governmental figures guarantee community's power to win votes. The major governmental demands to meet up with the selection guarantees often over-shadow economic rationales. The other inspiration for electrification is: the guarantee of improvement in public growth or enhancement in nature and condition of life [1]. Reliable access to electricity is a basic precondition for improving people's lives in rural areas, for enhanced health care and education, and for growth within local economies. At present, more than 1.5 billion people worldwide do not have access to electricity in their homes. An estimated 80% of these people live in rural areas; most have scant prospects of gaining access to electricity in the near future [2]. By 2030, according to International Energy Agency projections, the number of people without electricity is not likely to drop due to population growth. There are three technical approaches to bring electricity to distant areas:

A first option is simply to extend the national grid. In many countries, however, extending the national grid can be extremely costly. Non-urban areas are normally situated far from the national grid, therefore the heavy cost of increasing the transmitting collections usually make these tasks unfeasible. The terrain also increases expansion costs significantly. Mountainous areas with difficult access for machinery require more time and resources to install transmission lines. A third factor, the size of the demand, determines the cost per kWh of expanding the grid. A critical mass is necessary for a project to be viable.

Rural areas are generally small in size and their use of energy limited. In cases where there is no access at all to electricity, the potential demand must be calculated precisely. Although prices for grid extension differ from country to country, in many of them extension to an isolated village is viable only at a certain distance and as long as the village has a large enough demand to reach critical mass. Otherwise, off-grid electrification is the most cost-effective option. The connection to the national grid has some well-known advantages (including reliability, cheaper costs, and economies of scales) in compared with off-grid systems; however it is important to bear in mind certain issues:

1. Grid electricity tariffs are the same for rural consumers connected to the grid as they are for urban users, whereas costs are dramatically different. Hence, costly grid extension projects increase the overall price of the electricity for both urban and rural consumers.

2. The electricity offered by the power companies in developing nations often does not have the security of providing and quality of developing countries. Customers may have an entry to the electricity during restricted hours each day and power shutdowns or brownouts are common. Grid expansion increases the need, but if there is not a major increase in the energy generation capacity, including new consumers only worsens the scenario and decreases even more the quality of the service.

3. Grid extension is often a political tool. On the one side, grid extension electrifies more users per monetary unit than off-grid rural electrification programs, and faster. As a result, policymakers have a tendency to prioritize the extension of the grid to peri-urban areas in order to maximize their political support, or to provide electricity to urban populations that are more politically active and organized than rural ones. In fact, unrealistic political promises of future connection to the national grid are harmful for both consumers and the industry. People will be encouraged to wait for the grid for many years

rather than taking the initiative and supporting off-grid solutions; and companies may fear that their investment in off-grid solutions may prove worthless if the grid is indeed extended [3, 4].

A second option is an electricity mini-grid, which can offer central electricity generation at the regional level, using a village-wide submission network. Mini-grids offer potential for both household equipment and small businesses, and have the potential to become the most highly effective technical approach for accelerated non-urban electrification. Mini-grids also offer an optimal solution for utilizing localized renewable energy resources. Many locations offer excellent natural conditions for the use of solar photovoltaic (PV), wind, or small hydro power. In recent years, renewable energy technologies (RETs) have evolved dramatically, in terms of prices, efficiency, and reliability. Today, conservative calculations of life-cycle costs show that hybrid mini-grids, powered chiefly by renewable energy with a genset – normally working on diesel fuel, are usually the most competitive technical solution. However, translating this great technical potential into real success stories on the ground has turned out to be extremely challenging. Deployment of hybrid mini-grids involves complex financial and organizational questions. The bottlenecks for the sustainable success of mini-grids are not the technologies, but financing, management, business models, maintenance, sustainable operations, and socioeconomic conditions. Each community presents a cluster of characteristics and interests which will define one of the best technical solution according to local financial, social, and environmental terms [4, 5].

The third approach goes through the so called Energy Home System (EHS). The selection of this technology will depend mainly on the dispersion of the households and the types of load required. A village often can support the installation of its own small power system, but the distribution grid costs represent a big share of the project and its feasibility.

In contrast with a scattered population, covering a large area will entail higher connection costs, due to longer distribution lines. In these cases, stand-alone systems can be a better solution. Solar home systems (SHS), Pico-hydro systems (PHS), or wind home systems (WHS) are often the solution to provide energy access to detached households. . In these stand-alone techniques, the power generation is set up near to the fill and there are no transmitting and submission expenses. However, the total cost of energy tends to be higher due to the lack of economies of scale. To keep costs cost-effective, elements are reduced and capabilities are low, around 100W for SHS or 200W for PHS, mainly providing small DC equipment for lighting style and communication (radios, mobile phone charging, or B/W TVs) [4, 6].

1.1.1 What is a SHS?

A Solar Home System (SHS) is a small autonomous energy station, powered by a solar panel that provides electricity for services such as: lighting, radio, TV, and operation of small appliances to non-urban houses often without access to electricity plants. Primary solar house systems consist of a PV screen, a storage power supply, an assortment power charge controller accompanied by various end-use-equipment like fluorescent lights. Solar home systems are able to remove or reduce the need for candle lights, oil or power supply charging, and supply more convenience and safety, to improve indoor air excellent, a better excellent of light than kerosene lamps to read, and to reduce CO_2 emissions [7-11].

Solar-home-system technology has grown since the early 90's, cost was decreasing, and professional marketplaces were created. Simultaneously, inhabitants development was outpacing the capability of electric programs to boost non-urban power plants and creating nations were progressively acknowledging the economic complications of accomplishing full grid-based non-urban electrification. Government authorities and many NGO’s started to understand that solar home systems can supply least-cost non-urban electrification and can complement grid-based electrification policy [12].

Since then Solar Home systems projects were abundant in many developing countries. These projects were not always successful however, often problems occurred with the lifespan, maintenance and even the plain use of the systems. In some projects 2/3 of all installed systems broke down within the 1st year or simply never functioned properly at all [13]. This was often due to the harsh conditions in which the systems were placed, the low service-after-installment and the lack of context orientated placement of the systems. Traditional SHS's consist of separate components which makes the system more vulnerable to abuse and failure.

Solar home systems (SHS) sound to be the effective decentralized technology that can be used and promote in some developing countries, usually about the justification of cost-effectiveness [14, 15]. This shows the common understanding of solar-based technology that is in a good situation to meet the growing demand for power in the countries which are developing [16]. Photovoltaic or (PV) techniques after the energy crisis of of 1970's obtained favor in the international market [17]. However the fossil fuel lacks is short-lived and interest in PV quickly dropped. Ecological issues such as global warming triggered in parts by anthropologist actions mostly connected with using of fossil fuels, that have lately guided to improved consideration towards electricity in common, and solar techniques based on that these kind of technologies are clean [18]. Also restored issues of restricted oil and gas sources and international financial and governmental uncertainty concerned more attention. Also the newest terrorist strikes have been used in suggesting allocated renewables like solar rooftops. Furthermore, the initial ambiguous PV system energy balance, considered to enhance in favor of the system. In the case of grid-electrification, significant financial assistance is being offered for implementation of these systems [19-21].

Modern energy services are essential to support all three beams of maintainable development as mentioned in the review by the G8 renewable energy task force (2001),: economical, social and environmental. The review more notices that most energy services should develop and implement in a show with all aspects of the development process, e.g. energy and health, energy and communication. This reinforces this fact that high-quality energy and electricity services are linked together as fundamental factors in the public and financial growth. Thus it would be predicted that SHS, if implemented about this perspective, should contribute a service that allows accomplishment of economic, social and environmental. Therefore, this paper effort to find out whether SHS offer Cambodia the chance of conquering its advancement challenges, specifically as a source of energy for economic and social development. So, it is very crucial to consider that whether SHS could give rise to emissions reduction [22].

1.2 Objectives of Study

This study aims to investigate the various aspects of solar home system applied as a technological innovation along with its specific requirements. It also focuses on the feasibility of this system for the considered location in a techno-economic way. The various objectives of this work can be summarized as follows:

1- To review the energy situation in Cambodia and dissemination, usage and design of solar home system from the literature.

2. To do technical analysis and design of SHS for Cambodian rural area for 3 cases.

3. To investigate the economic aspects (annualized life cycle cost and levelised unit cost of electricity) of utilizing a solar home system (SHS) and its maintenance.

4. To use HOMER to design the SHS for each case and make a comparison between these results and those from theoretical calculations.

5. To compare the proposed SHS systems with grid extension by HOMER.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction

Cambodia with around 15 million populations is located in Southeast Asia. Around 85% of populations are living in rural areas and their primary livelihood is agriculture [23, 24]. The wet season from May to October and dry season from October to April, can be considered as the main seasons in Cambodia [25]. Based on the presented report the GDP per capita is found to be around US$874 in 2011 [26]. Hence, Cambodia is considered as the 16th lowest income country in the world [27].

Although the conventional energy resources of Cambodia are considerable, but energy resources are limited and to cover the energy demand, it is essential to use other energy resources that are cheaper and endless like renewable energy resource. Conventional energy resources of Cambodia are fuel wood, coal, forestry, fossil fuel, petroleum, oil and natural gas reserve [28-31]. Renewable energy resources of Cambodia include biomass, hydroelectric energy, wind and solar energy.

Towards development and augmentation of electricity generation previous studies focused on renewable energies potential to employ these energies in a feasible way and also to utilize technical methods for conservation of energy. In the context of the present study the renewable energy policies, potential of energy resources (Conventional and renewable energy resources) and concerned institutions in Cambodia are investigated, and the based dissemination and usage of solar home system in the Cambodia and other countries are reviewed.

2.2 Energy policy

All the villages of the Kingdom will have electricity of some form by the year 2020 and Enabling 70% of rural households to reach reliable electricity services by 2030, are one of the main policy and long-term determined targets by Royal Government of Cambodia (RGC) .The governments of Cambodia focus on providing energy services and improving the quality of life for rural population in their two main policies; Energy Sector Development Policy and Rural Electrification Policy. Development of renewable energies is one of the approaches that are adopted to meet the mentioned objective. Rural electrification fund (REF) subsidy and investment incentives are two main policy instruments that support the Energy Sector Development and Rural Electrification Policies financially. Based on the REF documents among the renewable technologies the solar home systems and mini/micro hydropower are the ones who are qualified for subsidies scheme [32-34].

2.3 Institutions

The main renewable energy Institution is in associated with the royal government of Cambodia and it is divided to three institutions of electricity of Cambodia (EAC), ministry of industries, mines and energy (MIME) and ministry of economic and finance (MEF). Among them, MIME is in charge of the energy issues in Cambodia. Generally, it develops energy policies, strategic plans and the standards (technical, safety, and environment). Cambodia’s electricity market is divided into 4 institutes (IPP, PEU, EDC and REE) and the rural electrification funds allocated to mini and micro hydro projects and solar home system are given to these institutions [35].

2.4 General consideration of energy resources in Cambodia

2.4.1 Conventional energy resources

Generally, the conventional energy resources of Cambodia are fuel wood, oil, natural gas and coal. Among the various natural energy resources in Cambodia, diesel and heavy fuel oil are mostly used to produce the needed electricity of the country. Fuel wood which is exploited from natural forest is one of the natural energy sources in Cambodia. More than 80 percent of the population depends on agricultural activity for their livelihood, thus the usage of wood and agricultural residues as the energy sources are significant. The average required fuel wood for one family is 5.27 ton/year in Kampong Chhnang province. There is not clear data to evaluate the amount of fossil fuel in Cambodia [29, 36, 37].

Estimation of oil and natural gas's amount is possible in portion of Cambodia's offshore of the Thailand's gulf with test drills. Test drills have revealed the potential existence of assumedly large offshore natural gas fields. Since neighboring Thailand has confirmed gas deposits, and has been commercially exploiting them, the probability is high that Cambodia will in the longer term be able to undertake similar explosion [29]. According to the ASEAN reports, natural gas reserve is estimated around 9.9 trillion cubic feet [28].

Coal deposit can be exploited from several provinces. Bituminous coal deposit can also be existed from offshore [29]. Poor level society uses hardly any charcoal and kerosene at all. Liquefied petroleum gas (LPG) is another conventional source that is mainly used by higher social class. The use of charcoal rapidly increased to 40 percent in 2010 but will steadily decline to 30 percent from 2013 to 2030. LPG is hardly used at the moment but will increase to 50 percent of the energy mix in 2030. LPG is going to replace charcoal and wood in future but it is included natural resources and limited so is better to use the renewable source energy [24]. Average LPG, charcoal and kerosene consumption for the two province of Kampong Speu and Svay Rieng are compared in Table 2.1.

Table 2.1: Fossil fuel consumption in Kampong Speu and Svay Rieng province [24].

	Kampong Speu		Svay Rieng	
	Fuel consumption	Produced energy (GJ/Year)	Fuel consumption	Produced energy (GJ/Year)
LPG (kg/month)	25.52	115,813	13.51	24,680
Charcoal (kg/month)	110.4	449,509	33.3	30,167
kerosene (liter/month)	5.78	80,486	5.59	60,951

The total required charcoal, LPG and kerosene in the rural area of Cambodia in 2020 are estimated to be 12,156TJ, 4671 TJ and 673 TJ, respectively. The estimated rural energy demand from charcoal, LPG and kerosene in Cambodia until 2030 is shown in Table 2.2.

Table 2.2: Estimated rural energy demand in Cambodia (TJ) [24].

	2007	2010	2012	2015	2017	2020	2022	2025	2027	2030
Total charcoal	5107	6796	8532	12,323	12,441	12,156	12,153	11,998	12,137	13,112
Total LPG	1885	2313	2512	3135	3591	4671	5570	7020	7763	8964
Total kerosene	1108	1166	978	843	735	673	674	731	767	717

2.4.2 Renewable energy resources

Since there is no official and comprehensive investigation of Cambodia's renewable energy resource, achieving sustainable energy development in which a fair distribution of renewable sources is meeting, is impossible.

The estimated potential renewable sources and the installed projects in 2004 are summarized in Table 2.3. Comparing the technical potential of the renewable energy resources and the installed projects in Cambodia, it can be found that there is still large amount of available renewable energies that can be utilized for electricity generation.

Table 2.3: Estimated potential and status of sustainable energy generation [29].

	Technical potential (GWh/year)	Currently installed projects (GWh/year)	Potential annual greenhouse gas abatement (kton CO_2 equ)
Hydropower	37,668	55	26,228
Biomass	18,852	0	13,146
Solar	65	1	44
Wind	3665	0	2556
Industrial energy	547	0	381
Residential energy	6591	29	4576
Total	67,388	85	46,931

It is also estimated that renewable energy sources of Cambodia can generate potentially 67,388GWh energy per annum. This energy is almost three times of the total energy consumed by the whole economy. It can be seen that the largest potential for electricity generation is estimated to belong to hydropower [38].

2.4.2.1 Solar energy

Cambodia receives a relatively high level of solar radiation throughout the year and the Sunlight hours are 5 hours average per day and consequently 1,825 hours per year. Starting to increase from January, the solar radiation in Cambodia reaches a maximum value in March and April. A value of 18.3 MJ/m^2-day is also reported for the average global irradiation throughout the whole area of Cambodia [39]. The average Cambodia sunshine hour is shown in Table 2.4.

Table 2.4: average Hours of sunshine in Cambodia(hrs)[40]

Month	Sunshine hour	Month	Sunshine hour
January	4.99	July	4.81
February	5.48	august	4.61
March	5.77	September	4.6
April	5.84	October	4.53
May	5.31	November	4.58
June	4.93	December	4.56

The solar PV technology has been used for lighting, radio, TV and telecommunication in the rural areas from 1997 in Cambodia. Based on the new energy and industrial technology development organization that used a 10-year annual average solar irradiation of 5.10kWh/m^2 per day and considering 0.02% of Cambodia's land area suitable for installing PV modules, the preliminary solar power generation potential estimated around 21GWh/day. Solar hot water potential is estimated to be 49.3GWh/day so applying the solar energy can reduce the need of other fuels such as fuel wood or charcoal. In comparison with the potential solar energy resources, the current utilization of solar power in the country is low. The total installed capacity was 205kW in 2002 and was increased to over 300 kW by the beginning of 2004 [38], and it is reported to be 700kW in 2005 based on the ASEAN [41]. Although To the best of authors' knowledge, the solar generated electricity in Cambodia is merely due to a hybrid system composed of a PV unit with 50 kW capacity as well as two biomass gas digestion each producing 35 kW. This shows that a great solar potential is still unutilized and there is an extensive room for more work and research. One of the next goals is to install 12,000 solar home systems (SHS) throughout seven of Cambodia's provinces from mid-2011 on. The main obstacles to the advancement of the industry in Cambodia are accessibility, awareness and affordability [38].

2.4.2.2 Review of usage and dissemination of solar home system

The most of the countries use the solar home system (SHS) to generate electricity especially in rural area and places that don't access to the national grid. Also the third globe is a huge market for solar power home Systems in which the power can create on houses in service of personal family members. A solar home system of 50 Wp with an everyday regular generate of 180 Wh matches the power usage of a common non-urban family which uses a number of lights, a stereo radio and a TV which is black and white, services which could significantly improve the total wellbeing in developing nations. Near 700,000 solar home systems already have been set up world-wide, only in Indonesia there are more than 10,000 home systems installed [42]. Some of these countries that are using SHS to generate the electricity are investigated in this paper. The German 'thousand roofs programs' set up PVs on the roof of household properties and businesses by the year 1999, and this is being followed by the 10,0000-roofs-solar-program [43]. In 1997 US Chief executive Clinton released the one thousand solar roofs programs. The Japanese government subsidizes set up of 70,000 PV roofs by 2005 [44, 45]. The US government released a Worldwide energy effort for financial year 2001, targeted at speeding up R&D of PV technology for non-urban development in developing nations [46]. Another target of 5000 MWp of recently set up PV capacity of 2010 in June 1998 Japan (G8 task force, 2001). By 2010 The European Union (EU) has designed to set up a thousand PV roofs, fifty percent in the EU and the rest in other developing nations [47]. By 2020 reinforced by PV The Netherlands has set objectives to increase electrical power to 1400 MWp [48]. British prime minister In March

2001 declared government financing of £100 million to market PV and the other electricity technology (G8 task force, 2001). Some different policy measures include: profile requirements and financial assistance, that are being used in the western world for motivating the usage of renewable [49-51].

Especially, 90 percent of the PV development occurs in European countries, Japan and USA, but lesser than 50 percent of the global set up potential is in these areas [52]. The biggest share is set up in developing nations. While the market for PV in designed nations soon will be soaked, interest will progressively move to the less western world [15]where according to[53] low electrification level offers the PV utilization a sensible place.

The Southern nations have not lagged so far behind to promote the technological innovation. By 2002 The native Indian government has set a committed focus on 1.5 thousand solar power roofs [54]. A common solar home system marketed by Ashden the Award-winner SELCO in Native Indian has a 35 Wp PV component and a 90 Ah/12 V battery to power for 7 W d.c. neon lighting about four hours per day and a plug. Lately the Solar Energy Foundation in Ethiopia has presented a 10 Wp program that has the ability for small LED lamps [55]. Africa nations like South Africa, The Morocco, Ghana, Namibia and Uganda have promised to back up SHS in the wish to understand the desire for worldwide electrification. This assistance can be shown in the guidelines and economical responsibilities to SHS tasks. Some cases of SHS tasks provided in some African societies. Most of the Southeast tasks although being reinforced by north aid and mostly pressed by north business owners based on reasoning and as a technological transferring measure. Thus the choices for setting up PV systems are affected by this kind assistance among the other alternate motives [56]. The result for investigating solar home system in Africa shows that The promise of participation of maintainable growth while at the same time lagging far behind in cost evaluation with conventional technology that makes SHS and PV technology in common as a policy-maker dilemma. Unluckily, Africa has the adverse maneuvering financial capacity and hardly can manage financial expensive errors. Therefore, this is crucial that technology implemented in Africa may not be only greatly effective economically these days but technically and institutionally developed. Change inside the power industry signifies that the public industry maintains a liability of electrifying the economically unappealing non-urban regions, the target market for SHS. At the same time the SHS might be enhanced economically, globally and technically, in local Africa this progression level still is inadequate for rationalizing implementation of the technological innovation. The expenses related to SHS in contrast to traditional technological innovation stay largely high for quite low assistance levels. Moreover, the availability of the restricted assistance can bring for the SHS a bad applicant for emissions reductions. Although strategic support that applied for SHS may validate based on this that it would link to a maintainable development course, their implementation in Africa must be restricted to those individuals who can manage for paying without demanding social financial assistance till the time when the real expenses are apposing with other technological innovation on the assistance level [1].

Outcomes are provided for the first year of tracking solar home systems in three regions in PR China. With a small number of calculated factors the function of the systems can be supervised thoroughly. The 45 Wp PV modules are somewhat over-sized for lighting style use only. Power balances did not expose any needlessly high system failures. All monitored solar home systems continue to operate without problems. Technically the data loggers worked well, but the regular data collection was more difficult than expected. Insolation measurements are unreliable in a number of cases. The monitoring fraction is low due to difficulties in retrieving the data from remote areas. There are more data gaps than expected, and none of the data series is uninterrupted. Data retrieval for the winter months was perceived as a potential problem from the start, and this fear turned out to be justified. Extra effort will be required in the future to retrieve data in April or May. Due to strong seasonal variations in the electricity demand and supply, the systems are oversized for most of the year. Usually, solar home systems are applied in tropical areas with smaller seasonal insolation variations. Because of the required over-sizing of the PV-module, application of solar home systems in northern and western regions of China is less efficient from a resource-use point of view than in tropical areas. However, it can still be the most cost-effective solution for remote rural electrification due to lack of alternatives. An advantage of over-sizing will be a long life expectancy of the battery. To meet current energy demand for lighting use only in the winter months, a module capacity of 35 to 40 Wp instead of 45 Wp would have been sufficient. Future television use throughout the year would require additional PV-power. With the current module size, a television can only be used when users are willing to accept that they cannot watch television in December and January. Most systems presently available on the Chinese market in the investigated regions include 25 Wp modules. With this module size, sufficient energy would be available for most of the year. But about 40% of the energy demand in December and January, and 10% of the annual demand cannot be met. Users should be informed beforehand that this will occur, so that they can prepare themselves by rationalizing energy use. Only about one third of the reference yield of electricity is actually consumed by the user. Most of this apparent inefficient use of the system is caused by the need for oversizing to cover the demand in the winter months. Module losses range from more than 20% in summer to about 10% in winter, probably due to the changing contribution of the temperature effect [57].

The World Bank/GEF supported Indonesia SHS Project which is to back up the distribution of 200,000 systems through the supply of (i) funding by taking part financial institutions to personal dealers(suppliers) of solar home systems the one who would allow the investment of the system by non-urban families and professional businesses bases on a sequel plan; and (ii) a GEF grant allocated to dealers (suppliers) based on an installed-unit [58].

Standalone photovoltaic (SPV) systems become more viable and profitable candidates for providing electricity to far places, mainly to some parts of Sabah and Sarawak in East Malaysia, the places that is receiving higher solar radiation [59-61]. This SPV program typically consists of a solar energy range, an operator with a maximum power point tracker (MPPT), assortment energy, an inverter and loads. In the program, the solar energy range converts solar energy rays falling on its surface into DC electricity. The operator with the MPPT helps to extract highest possible energy outside of the solar energy range regardless of the different solar energy rays and temperature along protection of battery energy from being overcharged and under-discharged. Battery power stores energy when the solar power range produces more energy than load demand or supplies energy to fill when the solar power range produces less energy than the load demand need during gloomy or stormy days or at night time. The inverter transforms DC into AC at a similar current level and regularity of the energy company for the convenient use of normal AC loads (electric appliances). Since outcome energy of a solar power range differs with varying weather conditions, the successful operation of the SPV system is to find out the maximum size of a solar power range and battery power to meet load demand. A system which wind energy is another source in addition to a solar array. In these mixed techniques, solar panel technology and wind energy complement each one; so the size of power supply is almost small and the duty of power supply is more limited than that in the SPV system. There are some researches and studies on the sizing of the SPV system as well. Totally there are 18 configurations of solar array and power supply which is defined in accordance with commercially accessible components. Then the fulfillment and the amount of the techniques were estimated for the specific load demand. The best size of the solar array and power supply will be chosen based on the proper balance between the LPSP and the program expense in those restricted options. However, the mixed use of battery power with two particular capabilities in one program is rarely implemented in actual applications [62]. The impact of tilt angle on the sizes of the SPV program had been examined for the specific given load demand, the optimal dimension the solar array and power supply was attained while the tilt angle was adjusted in accordance with the seasons, which reduces the set-up of the solar array [63]. One can decide solar set into two parts; grid-connected PV and stand-alone PV. The stand-alone PV is able to be set up in non-urban places. The cumulative grid-connected PV was 468.00 kWp , Up to 2004 [64] however this determine is mostly for the set-up of a 362.00 kWp project performed by Technology Park Malaysia in 2001 [65]. Although, the efforts from personal homes were little, about 9.00 kWp corresponds to only three set-ups. The primitive grid-connected PV set up in a household's home in Malaysia, where a 3.08 kWp solar panel was set up for the Tenaga Nasional Berhad that was created in Aug 2000, (TNB) officer’s home situated on Slot Dickson. The panel retrofitted on the top of ceiling protecting a place of 26 m^2. Several weeks later, one more set up was performed in Subang Jaya, by an outcome ranking of 3.12 kWp that protected a ceiling place of 24 m^2. The next set up was conducted a season after the second set up, on a home’s ceiling in Subang Jaya, along with a potential of 2.82 kWp. All these setups were finished by the TNB analysis group [65, 66]. It is possible now for Malaysian people to have solar-powered houses. Three house developments are providing high-end houses prepared with photovoltaic or pv (PV) techniques, in the Klang region. In its newest stage at Shah Alam in Setia Eco Park, Selangor. SP Setia is such as PV techniques in 20 of the 39 bungalows, that goes for around US$0.53mil. The 5 kilowatt peak (kWp) programs price each over US$56,667, and are predicted to produce US$50 value of power each 30 days. Developer Putrajana Perdana in Precinct 16 of Putrajaya, is providing PV segments in 15 bungalows varying in cost from US$0.96mil to the US$1.3mil. The each PV techniques regularly is around 5.4kWp. One more developer is going to integrate PV cells, into the sunshade on the roof of its low-density residence in the U-Thant region located in Kuala Lumpur. All these three developments are going to advantage from a 30 percent to 35 percent subsidy from the Malaysian Building-Integrated Photovoltaic or pv (MBIPV) project, that resources PV techniques for personal residences, professional structures and for housing development, for promoting solar energy. By Pusat Tenaga Malaysia this plan applies (PTM), and is partly provided by the U. s. Countries Development Program/Global Environment Facility. MBIPV financing assistance led to a lot more PV-equipped structures that provide as display sites: the Sri Aman university in Petaling Jaya; shoplots in Damansara, Uptown in Petaling Jaya, the six bungalow display models at Setia Eco Recreation area in Shah Alam, Putrajaya Perdana workplace in Putrajaya, a roof link bridge at Monash School in Bandar Sunway, Selangor; and four bungalows at Precinct 16 in Putrajaya. The MBPIV fundamental part is that most advantages of the community are Suria 1000. People here are able to bid for PV program financial assistance of up to 50 percent. So far this plan has given 30 homeowners the chance of producing solar energy which is happening rarely. Also project of The MBIPV supported the growth of the Ministry of Energy, Water, Ministry of Energy (LEO) Building and PTM Zero Energy (ZEO) Building. Both components integrated PV cells along with energy-conservation features [67, 68].

Bangladesh is highly rendered about the solar energy. In Bangladesh Solar Photovoltaic or (PV) program assume to be a suitable form of renewable energy in spite of the monsoon kind of environment. In Bangladesh the ultimate eye-catching advantage of the solar home system (SHS) is system of lightning. In non-urban Bangladesh people primarily use kerosene oil lights for lighting the houses at night. Dry cell battery power used for radio and progressively car battery power becomes popular for running TV close to lines areas where the the facilities of charging are also available. The price of kerosene and charging and the price of battery power are actually high and solar home system is able to contest with them in this specific field. To understand the economic durability of the solar house systems at chosen villages in Gazipur region six cases examined. Bangladesh has an approximated 60 000 people who are involved in the SHS industry, a figure that will grow larger as a bigger share of its non-urban inhabitants benefits access to solar electricity [69, 70].

2.4.2.3 Solar home system in Cambodia

Cambodia is still struggling with its violent past and has one of the lowest electric rates in Asia, while the costs of the available electricity even rank as one of the highest in the world. Extension of grid electricity lines is expensive and time consuming, especially in a predominately rural Cambodia. Therefore many households do make good use of rechargeable car batteries for lighting and television. This is however a far from ideal situation as the heavy batteries have to be charged several times a week, in a small shop where a throbbing generator is present. Due to this charging abuse and its poor use, the batteries are entitled to a short life, bringing unnecessary high costs and a low energy efficiency. Now, with oil prices rising and the economy improving people are in need of better power solutions, a Solar Home System (SHS) could fulfill this need [71].

Kamworks Ltd is a small Cambodian solar energy that is specialized in installing large professional solar systems and expanding to the consumer market, to contribute to their mission: "affordable energy for sustainable development". In coming years, the

Cambodian government stimulates the application of solar home systems through a grant boost. This and the lack of SHS currently in Cambodia creates a market opportunity for Kamworks and forms the motive for this graduation project, to design an innovative user-friendly Solar Home System for rural Cambodia. The Solar Home System was created by an elaborate analysis of the local context, where many Cambodian families were visited to map their energy needs, desires and living situation. Then a number of pilot SHS's were created on the basis of a preliminary design, to evaluate the technical functioning of the system and practical test the system in operation. The experiences of installation and production of an SHS could thereby already be taken into consideration early in the design process. Three systems were evaluated in the field by test families, whereby the product use, performance and appreciation was monitored technically by data logging and practically by a series of surveys. Based on this extensive design research the pilot SHS was further elaborated to a final SHS product design, ready for production. Thereby creating a unity in the system's appearance and use the result of this project is the design of three types of Solar Home Systems as one product family and one complete product. The SHS has become a true modern powerhouse for rural Cambodia. This is a distinctive desirable product of superb quality that matches with the Khmers culture, styling, and way of living, energy consumption and house situation. The system is easy to install, durable, strong and can be produced locally at Kamworks. The solar panel can be mounted securely to the house with the use of a new composite support. The technical components are enclosed in the Dragon box, a user friendly connection station with a high visual value for development of a product desire, which is a professional Commercial value in being unique and a functional value by defending the elements of the program. A charge regulator furthermore guarantees a safe use, an extended battery life and provides the users with the so desired energy feedback. Making the Kamworks solar home systems a secure energy source available for all, for an affordable prize. Kamworks had the desire to bring the SHS on the market soon; the outcome of this project enabled them to do so. Currently four systems have already been sold and installed according to the final designs. Kamworks is determined to continue with the production of the systems in the framework set by this project. Many customers are already eagerly waiting for what could be seen as the new generation of Solar Home Systems in Cambodia [72, 73].

Kamworks wants to deliver a high quality and appealing product, an integrated SHS specifically developed for the rural countryside of Cambodia and with high service. Besides a functional energy provider, it should be a desirable product. So instead of installing the technical components separately, they are enclosed in an indoor connection station (Homebox). This way the system will become more a 'product', that is distinguishable, user-friendly and with an appealing design to stimulate the proper care of the system. By concealing the technical components, Kamworks can furthermore guarantee the functionality of the product and optimize the total system's efficiency. Therefore a 1 year warranty can be given to the entire system. As principal the system will be installed by trained experts, to guarantee proper installment, mainly the orientation of the panel and connections of the system parts are fundamental to a supreme functioning system. The size of the SHS should match the energy consumption of the household according the capacity to pay [80, 81].

Three SHS versions are developed by Kamworks, according to an increasing energy demand and budget. A small 20 Wp system (Fig 2.1) is designed to power one or two lights as well as other small devices like radio and mobile phone. Also a medium sized SHS (40 WP, Fig 2.2) is intend for the basic energy needs like lighting the house, radio and a b/w TV. The third system is 60 WP (Fig 2.3).It is double size of the medium system and is designed for lighting a large house and the use of a color TV. The third system is the same as the 2nd, but has a 220V AC socket. This is perceived as more luxurious as it resembles grid electricity and any electrical appliance (if not consuming too much energy) can be connected to it. It can also directly replace the noisy inefficient generators of many affluent families[74].

Fig 2.1: Solar home system 20 Wp

Fig 2.2: Solar Home System 40 Wp

Fig 2.3: solar home system 60 wp

World bank (WB) has come up with a contract about Kamworks and a Chinese Enterprise for supervising installation, collecting payments and maintaining 12,000 SHS for 500 villages in 7 different regions of Cambodia (MIME/REF Project)[75, 76]. The solar organization qualifies for access to REF-grants, being on the accepted supplier record for solar home systems (SHS). Addition in the record is subject to verification by the REF that the solar house techniques promoted by the solar organization in Cambodia conform to REF quality requirements for SHS. The REF allows the grant of the solar home system for the first year of function is $100/set of 40 Wp. The solar industry evaluation study reports that that the exploitable industry potential for household techniques could be between 250,000 and 450,000 models, if capital cost buy down financial assistance of about $ 3.5 /Wp were provided. Roughly 85% of the industry appears to be in the 30-40 Wp techniques, that offer the potential to supply one (or two) lamps and a B&W TV. At the present time, three companies transfer and sell almost all solar products in Cambodia, such as techniques for telecoms and solar home systems; Khmer solar company, Metrofield technological innovation Co. Ltd and R.M Japan Ltd. An approximated 250 kWp of residential solar sections have been set up so far. Moreover, several worldwide PV producers such as Photowatt, Spend (Siemens), Solarex, unisolar and BP Solar have either a national or local existence [76].

CHAPTER THREE: DESIGN, METHODS AND PROCEDURE

3.1 Introduction

Most PV tasks for decentralized non-urban electrification programs are depending on stand-alone (off- grid) solar home systems (SHSs) generally in the potential varies from 35–100 Wp. Off-grid PV power plants, generally in the variety of 1–500kWp and with separate distribution network.

A normal SHS contains: PV module(s) which charge a battery bank to provide DC power to DC centered equipment such as CFL lights, TV, fan, etc. The charge operator is a fundamental piece of the SHS manages the power increase and outcome is that from battery it provides energy bank. The SHS can consider as an alternative energy to conventional energy sources (For Example: Oil, wax light, candlestick, battery energy powered flashlight, reprocessed power provide energy for using energy TV) and is used for supplying power for services in houses which are not attached to the lines. Ideally SHS are suitable for household lighting style and little power applications, but they have restricted opportunity for successful activity or community development, such as, providing the street lighting style, clean water and vaccine fridge.

3.1.1 SHS SECTION

A solar Home System consists of 3 principal parts (Fig 3.1); Energy generator, energy storage and distribution and energy load. These parts all have a specific function and are installed in various areas of the house; together they form a Solar Home System.

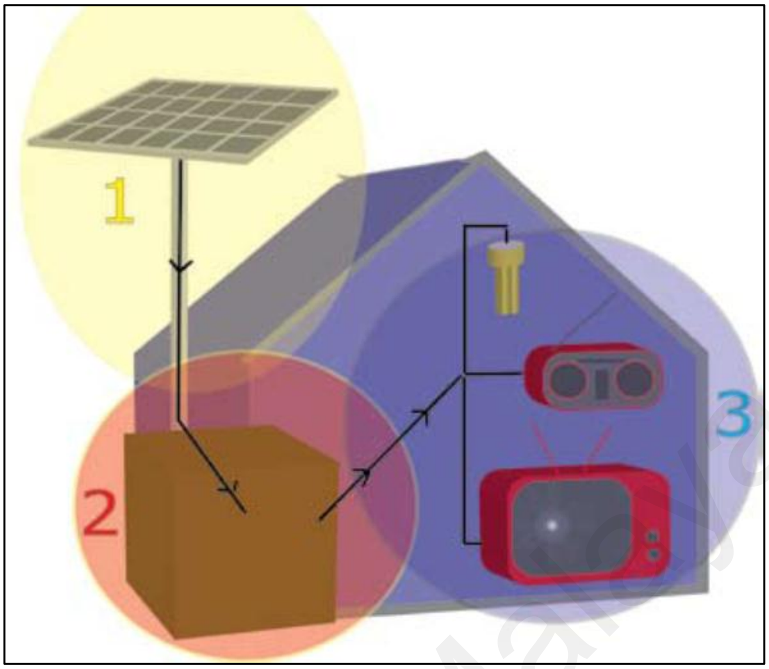

Fig 3.1: SHS sections

1. Energy generator

Energy generator consists of a PV solar panel and support structure. The PV panel generates electricity during the day and has to be firmly installed with a mounting system that is and resistant to harsh climate conditions for many years on/next to the house.

2. Energy storage and distribution

The energy, generated by the PV panel is stored in a battery; a charge controller operates sort of as the energy gatekeeper and protects the battery and connected appliances. By concealing these components in the Homebox, the customer cannot access the battery directly to connect devices, but does this thru the charge controller. In consequence the battery life can, with the right type selected, be prolonged up to 3-4 years.

The home box design (appearance) should take away the desire to open it. It will also have a warranty seal, which prevents opening by the customer and limits opening only for maintenance by a technician The Homebox should communicate the functioning of the system by a display that communicates intuitive; If it works (solar panel), how much energy is available (battery) and in case of malfunctions an error message (load). The charge controller can communicate such information and thus should be integrated with the home box. Principally the SHS operates at 12V, DC-power, if normal grid power of AC, 220V is desired, an inverter can be used to convert the power. This does affect the system's efficiency and is only sensible for larger SHS's.

3. Energy load

Lighting and small electrical appliances can be connected to the Homebox. Company sets up 4 set light areas and changes with the solar power home system to assure effective and protected lighting style in the house. The client should be able to link other electrical equipment, like television, VCD-player, stereo and cell phone recharges foolproof by himself.

Solar home systems usually supported by a grant (up to 90 percent of investment costs) under the Rural Electrification Fund(REFS) , which is designed in offering primary power solutions to areas residing in distant places where lines expansion is techno-economically unviable [77].

3.2 Design and operational aspects of SHS

Some of the important factors should be researched about SHS include: business economics of providing power services based on a life-cycle; and functions, management and servicing factors, both of them from the people, government and exclusive viewpoint, connected fill, power consumption or demand of designing, the local solar resource conditions, moreover submission of fill facilities in a town are key elements which impact the business economics of the provided power from SHS options. In the same way, option after sale services, option finance and the other financial rewards might consider while looking for SHS. Other important features are related to SHS in replace of national grid included, Freedom and independence to the customer to handle its plenty and power intake, Usually possessed by the customer, hence the customer is accountable for all servicing, alternatives and servicing need throughout the useful life of the program, Developed to support set types of household plenty mostly made up of style of lighting and some little equipment such as TV or radio, developed along with autonomy to support all plenty regularly all the times in the year with probability of PV power is not utilized if battery power has been completely billed because of the program that is not used for some days, Use of single PV component only, Functions in off-grid and stand-alone method only, Use of personalized DC equipment, usually with power efficient styles, PV component set up at person's assumption, hence vulnerable to robbery, wanton damage, tampering due to its easy availability, Allocated systems demanding O&M services at spread places and Energy intake and fill management within the control of the customer, usually results deep release of battery power [77].

3.2.1 Design

Often an SHS is designed to supply reliable electricity advantages to only one family without letting any capacity shortage or loss of peak load at any season. Hence, power supply size often incorporates 2/3 days of autonomy in case solar radiation is not enough because of partial or fully gloomy times to charge power supply in only one day during specific periods of the season [78].

3.2.1.1 A basic solar home system

Basic of solar home system are included PV module/ panel, support structure, charge controller, battery and Electric appliances/ Load.

1. PV module/ panel: A number of photovoltaic cells connected and installed together, in a enclosed unit of practical size.

2. Support structure: Used to install the PV segments in place. Based on the application, the PV segments can be installed on homes, in building components and in the open areas.

3. Charge controller: boundaries the amount at which electricity is added to or drawn from electric batteries. It stops overcharging and it may avoid against over current, which can decrease the performance of power supply, and may present a security risk. To protect battery life it also prevents complete draining or "deep discharging", and performs controlled discharges, that depend on the technology of the battery. Many charge controller systems display operation data. Simple charge controllers stop to charge a battery while they surpass a set of high voltage level, and re-enable to charge for when battery power current falls back below that stage. Pulse width modulation (PWM) and maximum power point tracking system (MPPT) technology are highly digitally practical; modifying asking for rates depends on the battery's stage, for allowing charging for getting closer to its highest possible space. Charge remotes also may monitor battery power temperature to avoid heating up and improve the use [79].

4. Battery: Two or more electrochemical cells linked in sequence that store substance power and can make it accessible as electrical power. Battery power is able to energize when the substance responses are reversible; in this case they are energized by running an asking for present via power supply, but in the other way of the release present. There are many kinds of electrochemical cells, such as the traditional wet lead-acid, the modern enclosed lead-acid and the dry-cell like lithium-ion(Li-ion) are the most typical. Moreover features differ because of many factors such as inner chemical make-up, present

strain, and temperature. The power supply choice relies upon highly on its application, environment and prize [80].

5. Electric appliances/ Load; like lighting, television and radio from the load for the system and demand the amount of electricity used at any given time (Fig 3.2,).

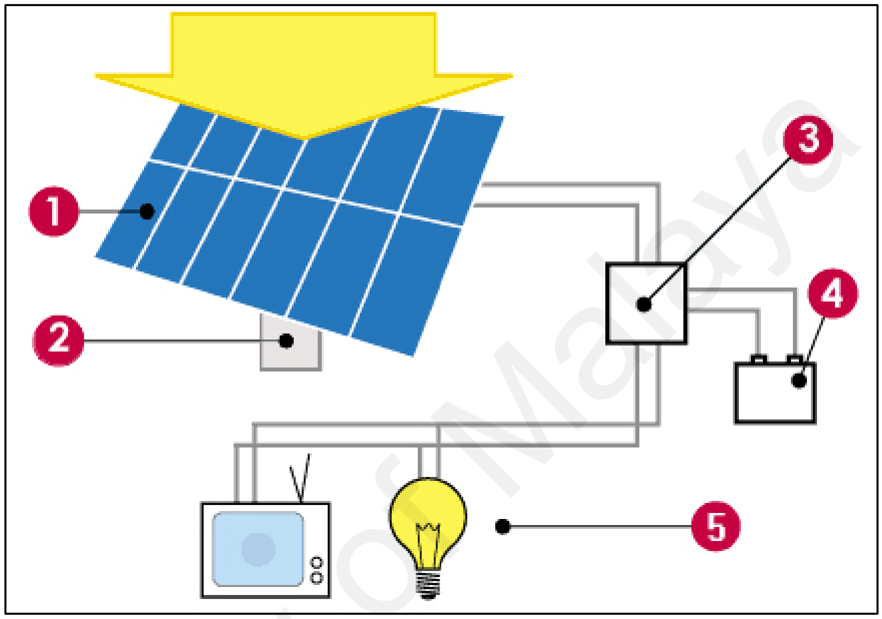

Fig 3.2: Configuration of a Solar Home System

3.2.2 Efficiency

An SHS is a DC program which produces shops and able to use DC power often at the same current stages during the pattern. Loosing of power from creation for intake pattern in this program is largely because of natural failures affiliated with each element in the program such as a power supply (charging and discharging efficiency), cost operator and the end-use equipment such as laminar with CFL and a small inverter. A battery power financial institution in an SHS generally uses individual battery power of 12 V, 20/40/75 Ah potential each [74, 81, 82].

3.2.3 Applications

An SHS is developed to support set linked plenty mainly for household lighting style programs with the choice of using little potential DC equipment such as fan or TV/radio. The DC equipment used in an SHS is exclusively constructed for this objective and may not always comply with excellent requirements [83, 84].

3.2.4 Operation and maintenance (O&M)

Generally SHS is published through possession design along the customer of the SHS operates programs and then requires whole pressure of O&M throughout the useful lifestyle of the program. Also SHS is able to provide for the lease foundation for decreasing the pressure of advance along with the O&M expenses to the customer, but these situations are unusual in Cambodia. In the insufficient an efficient after-sales-service system for SHS, the customer might discover it complicated for using the SHS as he/she doesn't normally have an entry to excellent spare parts and qualified experts to perform repairs/replacement tasks in an SHS. The allocated places on the SHS customers may also present an issue for getting O&M solutions [84].

3.2.5 Capital cost

Capital price of SHS should be in contrast to other systems like national grid or microgrid system so an SHS uses little potential PV segments (18/37/50 Wp) as in comparison to microgrid which uses 75/80/100/120 Wp and although larger potential PV segments for forming a range. The transformation effects along with device price with regards to $US./Wp are required to be much better in huge potential segments as opposed to little potential ones. In the same way, the device price of power supply with regards to $US./Ah is less for huge size power supply which uses in microgrid then for those uses in

SHS. Such price discount rates, as the style and the amount grows, is because of changes in development procedures and some changes in feedback costs which are making a microgrid more aggressive (on the basis of $US./Wp) as opposed to SHS. The additional price of inverters and submission system that is used in a microgrid may however, balanced out these price benefits [74].

3.2.6 Assumption and formula design of SHS

The techno-economic analysis is provided in this research is based on developing SHS for the amounts of houses as well as the kind of power services and research on the reasons for yearly expenses (annual costs) and the price of generation of electricity. The presumptions bellow, are used for developing the SHS:

1. The kind and number of appliances as along with their length of utilization in a house maintained by an SHS should be regarded. The DC electricity may vary based on the different stages of efficiencies of inverters which used in SHS. This element will impact the size of battery and PV in SHS.

2. PV and battery capacity that require to service a single family is estimated for SHS using common system design assumptions considering (i), design days of autonomy for no/low Sun days (ii) efficiencies of all of the components, (iii) field related losses because of temperature, shadow, dust and mismatch in cells in a component, (iv) depth of discharge of battery. By increasing the battery capacity less over design of PV system is required and vice versa. Computation of tilt angel is not considered and a rough estimate of the array dimension is done.

3. Households serviced by SHS use DC appliances. Though, CFL is used for household lighting style in the situations. Since CFL is an AC device, it needs a little inverter placed within the luminaire which can be used in case of an SHS.

4. An inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage (12V) as your battery. For stand-alone systems, the inverter must be large enough to handle the total amount of Watts you will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting. For grid tie systems or grid connected systems, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation [85].

5. Efficiencies of battery and inverter enhance by their sizes and are shown in measurement SHS. Similarly, these efficiencies took as 85 percent of battery power and 90 percent for inverters in SHS.

6. Often charge controllers can be used along with SHSs which have a performance in the variety of 80–85 percent.

7. Although losses because of dust remain and temperature for SHS, this differs because of mismatch due to better relate to tissues used in capacity PV modules in an SHS. The efficiency of mis-match factor is assumed to be 85% and the efficiency of temperature is assumed to be 90% in SHS. The efficiency of Dust derating is taken to be 90% for SHS[77].

8.The next operational factors i.e. Availability of solar radiation, annual times of function, and daily business hours, etc. can be considered for SHS [74]. The latitude of Cambodia is 12.4317° N, 104.5291° E and total average sunshine hours is 5 h in a day that is defined as the total amount of incident solar radiation received on a unit surface area in a day. The result indicates that Cambodia has great solar energy potentials and solar radiation environment of Cambodia is fully affected by the monsoons. , From January to Jun, Cambodia has the maximum sunshine hours and an average of 5.387 hours so the weather is usually hot and the household needs fan so need to use more electricity and energy requirement. From July to December, Cambodia has minimum sunshine hours and average of 4.615 hours so the average hours of sunshine is 5 hours [39, 40].

9. Determine depth of discharge (DOD) for battery is selected from manufactures data sheets of estimate from type of battery (0.7)[77, 86].

10. The solar charge controller is typically rated against Amperage and Voltage capacities. Select the solar charge controller to match the voltage of PV array and batteries and then identify which type of solar charge controller is right for your application. Make sure that solar charge controller has enough capacity to handle the current from PV array. For the series charge controller type, the sizing of controller depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (series or parallel configuration). According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array (selected from solar module catalogs), and multiply it by 1.3[85].

For the purpose of the analysis, the 3 cases with different loads (low, average and high) and hours of operation per day are selected:

(a) Case A: Village of N households requiring 1×9WCFL, each to be used for 8 h daily (a connected load of 9 W per household with an energy requirement of 72 Whr per day).

(b) Case B: Village of N households requiring either (i)4×9W CFL Or (ii) 2×9W CFL+1×18W fan or (iii)3×9W CFL+1DC socket for radio/cassette recorder (9w), each to be used for 3 h daily(energy requirement of 108 Whr per day)

(c) Case C: Village of N households requiring 7×9 CFL Or 2×9 W CFL + 2×18 W fan + 1× 9 W radio each of these loads is to be used on an average for 4 h daily(energy requirement of 252 Wh per day).

For designing SHS, a platform situation with a group of N houses are regarded. All families have a load of L Watt (For an ongoing operating load, the load is the average load) and is needed to function this load for “h” hours per day. For the objective of this research, a unique situation of household lighting is regarded as originally most of the non-urban PV applications are basically limited to lighting style. Technical analysis of solar home system methodology is in accordance with wind and solar power systems: design, analysis, and operation and Eco-Architecture: Harmonization Between Architecture and Nature [74, 87].

1. Determine power consumption demands

The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as follows:

Calculate average load (L) in watts, or the total daily load (D) in Wh

For a continuous running load, the load is the average load.

2. Total AC power required (P_r^{AC}) (Watt AC):

$$P_r^{AC} = P_{r,CFL}^{AC} \text{ (Watt AC)} \times \text{Number of 9 W CFL used} \tag{3.1}$$

3. Total AC energy required per day ($E^{AC}_{T,day}$) (AC Wh/day)

$$E^{AC}_{T,day} = P_r^{AC} \text{ (Watt AC)} \times h \tag{3.2}$$

4. Total DC energy required per day ($E^{DC}_{T,day}$) (AC Wh/day):

$$E_{T,day}^{DC} = \frac{E_{T,day}^{AC}}{\eta_{inverter}} \tag{3.3}$$

5. $\text{Days of autonomy} = \dfrac{2 \times \text{hours daily}}{3}$ (3.4)

6. Calculate average power need from array

Respectively, average load is used for 8 hours for case (a) and 3 hours for case (b) and 4 hours for case (c).

Increase load to account for electrical losses in inventor, batteries, charge controller,

$$\text{Power needed }(Wh) = \frac{8L(Wh)}{\eta_{batt} \times \eta_{inverter} \times \eta_{cc}} \quad (3.5a)$$

$$\text{Power needed }(Wh) = \frac{3L(Wh)}{\eta_{batt} \times \eta_{inverter} \times \eta_{cc}} \quad (3.5b)$$

$$\text{Power needed }(Wh) = \frac{4L(Wh)}{\eta_{batt} \times \eta_{inverter} \times \eta_{cc}} \quad (3.5c)$$

$\eta_{batt} = 0.85$, $\eta_{inverter} = 0.9$, $\eta_{cc} = 0.85$

7. Calculate energy from x watts of installed photovoltaic power:

$$\text{P}_{\text{generated}}\ (Wh) = xW \times sunhr \times \eta_{temp} \times \eta_{dust} \times \eta_{micmatch} \quad (3.6)$$

For latitudes of 12.4317° N, 104.5291° average sunhrs=5hrs

$\eta_{temp} = 0.9$, $\eta_{dust} = 0.9$, $\eta_{mismatch} = 0.85$

8. Power generate must equal power needed by load.

$$\text{Power generated (Wh)} = \text{power needed from load }(Wh) \quad (3.7)$$

9. Calculate amount of installed power needed.

Respectively for case (a), (b) and (c)

$$xW \times sunhr \times \eta_{temp} \times \eta_{dust} \times \eta_{mismatch} = \frac{8L(Wh)}{\eta_{batt} \times \eta_{inventer} \times \eta_{cc}} \quad (3.8a)$$

$$xW \times sunhr \times \eta_{temp} \times \eta_{dust} \times \eta_{mismatch} = \frac{3L(Wh)}{\eta_{batt} \times \eta_{inventer} \times \eta_{cc}} \quad (3.8b)$$

$$xW \times sunhr \times \eta_{temp} \times \eta_{dust} \times \eta_{mismatch} = \frac{4L(Wh)}{\eta_{batt} \times \eta_{inventer} \times \eta_{cc}} \qquad (3.8c)$$

10. Earned xW from put Power generate equal power needed by load.

$x = 3.58L Wattes$ For case (a) (3.9a)

$x = 1.34L Wattes$ For case (b) (3.9b)

$x = 1.79L Wattes$ For case (c) (3.9c)

Need about 3 times for case (a) and 1 time for case (b) and (c) the amounts of photovoltaic panels as a continuous load.

11. Number of PV panel

$$\text{Number of PV panel} = \frac{\text{xW}}{\text{nearest and available PV panel}} \qquad (3.10)$$

12. $\text{Total PV capacity} = \text{number of panels} \times \text{panel}$ (3.11)

13. Inverter sizing

$$\text{Inverter sizing} = \text{P}_\text{r}^{\text{AC}} \text{ (watt)} \times 25\% + \text{P}_\text{r}^{\text{AC}} \text{ (watt)} \qquad (3.12)$$

14. To calculate battery capacity required to service each of the household should be change load (Watt) to load (Ah).

$$\text{Load (Ah)} = \frac{\text{L(W)} \times \text{h}}{\text{V} \times \eta_{\text{batt}} \times \eta_{inverter}} \qquad (3.13)$$

15. Battery capacity can be determined as

$$\text{Battery capacity } (Ah) = \frac{Load(Ah) \times \text{Days Autonomy}}{DOD} \qquad (3.14)$$

16. Solar charge controller sizing

$$\text{Solar charge controller rating} = \text{Isc} \times 1.3 \qquad (3.15)$$

3.3 Economic analyses of solar home system

For the economic analyses of the proposed solar home system, the annualized life cycle costs (ALCC) method is used and it takes to into consideration the complete range of costs, annual electricity generation and makes the levelised unit cost of electricity.

3.3.1 Assumptions

1. The discount rate will depend among others on the general level of interest rates in the country net of the inflation rate, or how people in general value future benefits and losses. An initial economic assessment for the different technologies was conducted. The analysis, performed in constant dollars, over a lifetime of twenty years, with a discount rate of 5.25%(2008) and inflation rate of 5.5% (2011) shows that all options have a potential positive Net Present Value (after cost reductions), which indicates that all are sound investment opportunities for the country [88-90].

2. The price of appliances (CFL 9W) is estimated US$10 from appendix A.

3. The price of PV module, battery and charge controller are selected from catalogs in appendix B, C, and D.

4. The balance of solar home system (BOS) price is related to size of PV module, battery and company. Companies usually consider 10% of total price of solar home system as system balance and 1% as miscellaneous cost (C_m) that is included PV array support, PV field fence and electric cables. [86].

5. Life time of PV module, battery, charge controller, Appliances and Balance-of-systems respectively are 20,5,5,10,10 years [77, 86].

6. Annual O&M costs is estimated 2% of total price of solar home system [86].

7. The capacity utilization factor (CUF) is estimated 0.9 which combines outages of systems and non-utilization due to different explanations [77].

Economical analyses of solar home system methodology is in accordance with solar engineering of thermal processes [91].

3.3.2 Annual cost of SHS

1. The annualized life cycle cost (ALCC) for an SHS is calculated by summing up costs of all its components (i.e. PV module, battery, charge controller, O&M cost, miscellaneous cost, balance of solar home system and appliances) multiplied by their respective capital recovery factors.

$$ALCC_{SHS} = C_{0PVSHS} \times CRF_{PV} + C_{0battSHS} \times CRF_{batt} + C_{0CC} \times CRF_{CC} + C_{0appl} \times CRF_{appl} + C_{O\&M-SHS} + C_{0bos} \times CRF_{bos} + C_m \quad (3.16)$$

2. The capital recovery factors (CRF) is calculated using the expression, where i represent the chosen discount rate and n is the life of the particular component being considered. Any other annual costs towards O&M that include service fee of a mechanic/technician, replacement of switches, fuses, etc.

$$CRF = \frac{i \times (1+i)^n}{\left[(1+i)^n - 1\right]} \quad (3.17)$$

3. Total capital cost of all component (C_0):

$$C_0 = C_{0PVSHS} + C_{0battSHS} + C_{0CC} + C_{0appl} + C_{0bos} + C_m \quad (3.18)$$

4. The present value of battery replacement

If the system want to calculate for life time of 20 years (PV life time),it is necessary to compact the present value of battery replacement. x is the inflation rate and i is the discount rate. The present value of battery replacement costs depends on the number of battery replacements during the lifetime of the PV system.

$$CRF(x, y, N) = \sum_{j=1}^{N} \frac{(1+x)^{j-1}}{(1+i)^j} \quad (3.19)$$

Where v is the number of battery replacements computed from the battery lifetime n and PV system lifetime N as:

$$v = \text{int}\left(\frac{N-n}{n}\right) \tag{3.20}$$

5. The present value of annual operation and maintenance costs of the PV system can be computed with the relation:

$$C_{O\&M-SHS} = 0.02 \times C_O \times CRF(x, y, N) \tag{3.21}$$

6. Annual electricity generation (kWh)

$$\text{Annual electricity generation (kWh)} = P_{pv} \times \frac{G}{G_{ref}} \times 365 \tag{3.22}$$

7. Cost of electricity from SHS

The levelised unit cost of electricity from an SHS ($LUCE_{SHS}$) is estimated:

$$LUCE_{SHS} = \frac{ALCC_{SHS}}{W_P \times sunhr \times 365 \times CUF} \tag{3.23}$$

3.3.3 Viability of SHS compared to nation grid from the user's perspective by HOMER

In order to see the applicability of the above analysis for communities residing in Cambodia climatic zones and receiving different amount of solar radiation, an analysis was performed using HOMER (Hybrid Optimization Model for Electric Renewables – developed by National Renewable Energy laboratory, USA is an optimization model for distributed power. It simulates the operation of a system by making energy balance calculations for each of 8760 hours in a year.) for taking hourly load values and simulating the performance of the system throughout the year for each of three cases selected. The other results earned by HOMER are 20 years projected cash flow and cash flow summary for selected battery, monthly average electric production, PV output; frequency histogram, monthly statics, and battery bank state of charge and compare SHS for 40 households with grid extension for each of cases.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Results of technical analysis:

The values of battery and PV capacity for SHS estimated using the above equations along with their respective input parameters and assumptions are presented in table 4.1.

Table 4.1: sizing SHS for case A, B and C

		Case A	Case B	Case C
Number of households	Units	40	40	40
AC Power required per CFL (P_r^{AC})	Watt AC	9	9	9
Number of 9 W CFL used	nos	1	4	7
Total AC power required	Watt AC	9	36	63
Hours of operation per day	h/day	8	3	4
Total AC energy required per day	ACWh/day	72	108	252
Inverter efficiency	Fraction	0.9	0.9	0.9
Total DC energy required per day	DCWh/day	80	120	280
Operating voltage	VDC	12	12	12
Battery efficiency	Fraction	0.85	0.85	0.85
Days of autonomy	Day	6	2	3
Charge controller efficiency	Fraction	0.85	0.85	0.85
Power needed	DC Wh	110.73	166.08	387.54
Efficiency of temperature	Fraction	0.9	0.9	0.9
Efficiency of dust	Fraction	0.9	0.9	0.9
Efficiency of mismatch	Fraction	0.85	0.85	0.85
Average sun hours	h	5	5	5
Power generated	DC Wh	110.73	166.08	387.54
X	DC Wh	32.16	48.24	112.57
Nearest panel	watt DC	40	55	65
Number of PV panel		1	1	2
Total PV capacity	watt	40	55	130
Inverter sizing	watt	11.25	45	78.75
Load	Ah	7.84	11.76	27.45
Depth of discharge (MDOD)	Fraction	0.7	0.7	0.7
Battery capacity	Ah	67.2	33.6	117.64
Nearest available battery size	Ah	12v,73.6h	12v,40h	12v,180ah
Total short circuit current of PV array (isc)	A	2.57	3.31	3.92
Solar charge controller sizing	A	3.34	4.3	10.19
Selected solar charge controller	A	5	5	15

According to table 4.1, households in Case A that use 1 light of 9W CFL for 8 h (energy requirement of 72Wh per day) each would require a PV capacity of 32.16 Wp (or an SHS of 40 Wp PV module). Households in Case B that use 4 lights of 9W CFL Or (ii) 2×9W CFL+1×18W fan or (iii)3×9W CFL+1DC socket for radio/cassette recorder (9w), each to be used for 3 h daily(energy requirement of 108 Whr per day) would require 48.24 Wp per household (or an SHS of 55 Wp PV module). Households in Case C that use 7×9 CFL Or 2×9 W CFL + 2×18 W fan + 1× 9 W radio each of these loads is to be used on an average for 4 h daily(energy requirement of 252 Whr per day) would require 112.57 Wp per household (or 2 SHS of 65 Wp PV module)(appendix B).

The other comparison is between the battery capacities of each case. Voltage of each battery is 12 V. The battery capacity for case A is 67.2 Ah so the nearest available battery size from catalogue in appendix C is 12v, 73.6 Ah. For case B the battery capacity is 33.6 Ah so the nearest available battery size is 12v, 40 Ah and finally for case C it is 117.64 Ah so battery size of 12v, 180 Ah is chosen. Total AC power required in case A ,B, and C are 9,36 and63 watt and hours of operation per day is for case A (8),case B (3) and for case C (4) hours respectively. Although in case A the required total AC power is less than case B but because of 8 hours of operation per day the battery capacity is more than case B. This chosen operation hours per day for case A is based on the weather in some places which is usually cloudy; so they don't access to the sun radiation and they have to use more hours operation from the SHS while they can't expect a high load. For case C because of the high required power, high battery capacity (180 Ah) is selected. Solar charge controller for cases A and B is selected 5A and for case C 15A (Appendix D).

If a village with 40 households in Case A is to be serviced with SHS, a total of 1.6 kWp PV (40 households of 40 Wp SHS each) capacity would be required. For case B with 40 households, a total of 2.2 kWp PV (40 households of 55 Wp SHS each) capacity would be required. Finally the capacity of SHS for case C would be required a total of 5.2 kWp PV (40 households of 130 Wp SHS each).

The other application of case A is for places that the weather is not usually hot so extra load is not needed to use fan or other cooling systems; in other words, it is more suitable for places with average solar irradiation of lowest area (4.7 kWh/m2/day) and minimum sunshine hours of 4.615 hours in Cambodia.

Cases (B) and (C), are more suitable for the places with hot weather because in hot weather households need to use fan or cooling system. These are designed for maximum sunshine hours and average solar irradiation of highest area. In Cambodia, average of maximum sunshine hours is 5.387 hours and average solar irradiation in the highest area is 5.3 kwh/m2/day. But on the other hand, all of design in additional useful technical analysis for different places should be economical so this study has done an analytical investigation on economical aspects of each SHS.

4.2 Results of economic analysis:

C_0 and CRF with their respective subscripts, represent capital costs and capital recovery factors for PV, battery, charge controller and appliances. The annualized life cycle cost (ALCC) for PV module of 40 Wp SHS,55 Wp and 2×65 Wp SHS at specified values of input parameters are estimated to be US$ 74.44, and, US$ 64.26 and US$102.38 respectively (table 4.2).

Table 4.2: Annual costs (ALCC) and levelised unit cost of electricity (LUCE) from 40 Wp, 55 Wp, 65 Wp in SHS.

Components	Capital cost(US$)	Life (years)	CRF (fraction)	Annualised cost(US$)
SHS –Model1				
Module (40Wp)	136.5	20	0.07271	9.92
Battery (12V,73.6Ah)	217.07	5	0.1985	43.08
Charge controller(5Ah,12v)	12.5	5	0.2325	2.91
Appliances (1×9 W)	10	10	0.1311	1.31
Balance-of-systems	36.6	10	0.1311	4.79
Miscellaneous cost	4.16			4.16
battery replacement	651.21		0.9937	647.1
Annual O&M costs				8.25
Total annualised costs	416.83			74.44
Annual electricity generation (kWh)				74.46
LUCE (US$./kWhr)				1.13
SHS -Model2				
Module (55Wp)	169	20	0.07271	12.29
Battery (12V,40Ah)	139.65	5	0.1985	27.72
Charge controller(5Ah,12v)	12.5	5	0.2325	2.9
Appliances (4×9 W)	40	10	0.1311	5.24
Balance-of-systems	32.1	10	0.1311	4.21
Miscellaneous cost	4			4
battery replacement	418.95		0.9937	416.31
Annual O&M costs				7.9
Total annualised costs	397.25			64.26
Annual electricity generation (kWh)				102.38
LUCE (US$./kWh)				0.71

Table 4.2 Continued				
SHS -Model3				
Module (2×65Wp)	400	20	0.07271	29.08
Battery (12V,180Ah)	285.43	5	0.1985	56.65
Charge controller(15Ah,12v)	19	5	0.2325	4.41
Appliances (7×9 W)	70	10	0.1311	9.17
Balance-of-systems	70.4	10	0.1311	9.23
Miscellaneous cost	8.5			8.5
battery replacement	856.29		0.9937	850.89
Annual O&M costs				16.96
Total annualised costs	853.33			134.02
Annual electricity generation (kWh)				241.99
LUCE (US$./kWh)				0.99

The economic analysis from table 4.2 shows the annual electricity generation that is the total number of kilowatt-hours produced within a structure within a year for case A, B, and C respectively are 74.46, 102.38 and 241.99(US$./kWh).Total initial capital cost is the budget spent over the purchase of PV module, battery, charge controller, appliances and balance of systems to be used for each case to generate the electricity. In other words, the total cost needed to bring a project to a commercially operable status include 416.83 for case A , 397.25 for case B and 853.33 (US$) for case C. Finally, the most important economical part that is calculation and analysis of levelised unit cost of electricity (LUCE) is done. LUCE for case A, B, and C are 1.13, 0.71 and 0.99 US$./kWh respectively. According to the result of LUCE from table 4.2, it is obvious that the best economical case is case B because of having the lowest amount but it does not mean that case B is the best technical design because the amount of operation hours and PV module should be considered. If the system is going to be analyzed for a period of 20 years, battery replacement is a factor that should also be taken into account.

4.3 Result by HOMER

Sensitivity analysis was subsequently performed for each of cases with annual average of monthly solar radiation. The technical as well as economic assumptions for performing analysis using HOMER were kept 90% same as the result from analytical calculations. For case A levelised unit cost of electricity (US$./kWh) is 1.13 from calculation and 1.3 from HOMER (fig 4.1.).

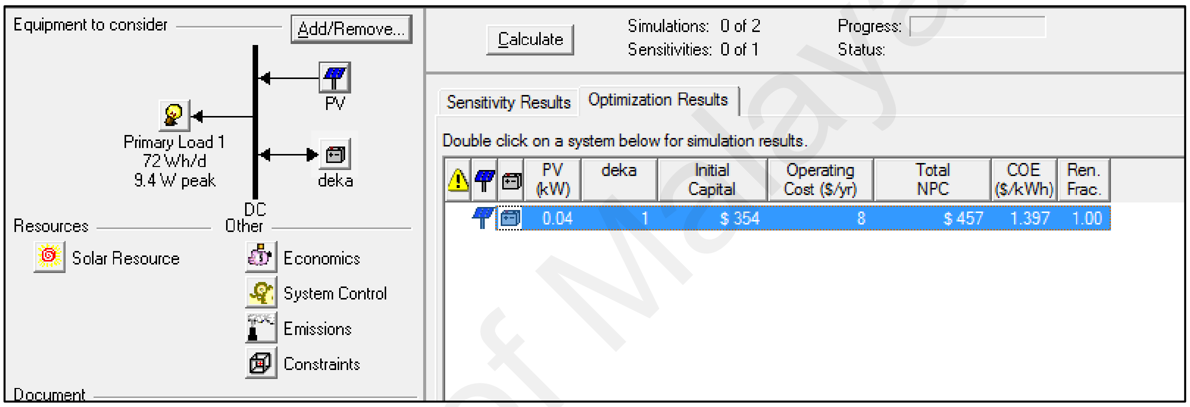

Fig 4.1: Optimization results for case A by HOMER

20 years projected cash flow for selected battery that is the difference in amount of cash available at the beginning of a period (opening balance) and the amount at the end of that period (closing balance) is analyzed by HOMER (fig 4.2). Also cash flow summary for case A that includes capital, replacement and operating of net present cost (fig 4.3) is planned.

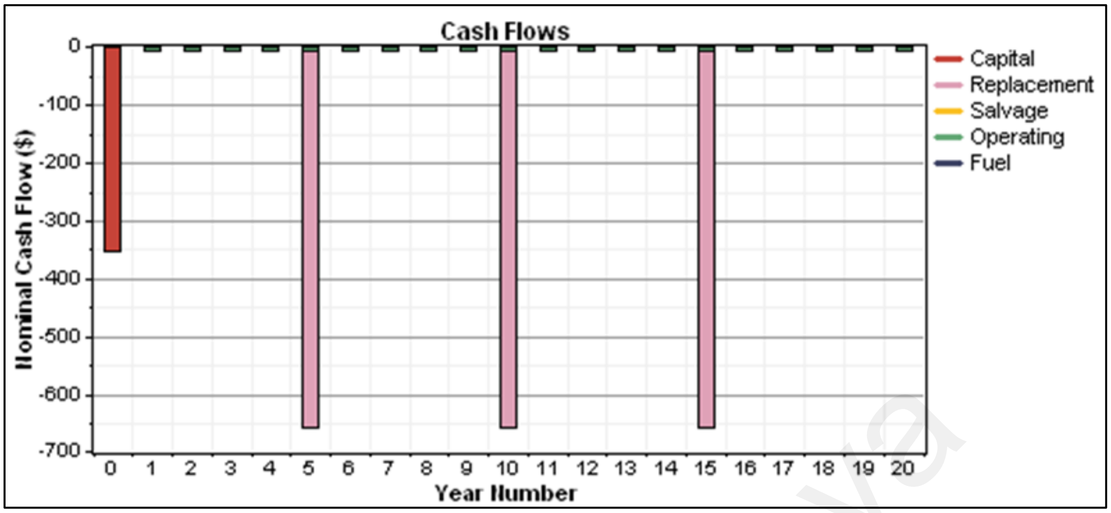

Fig 4.2:20 years projected cash flow for selected battery case A

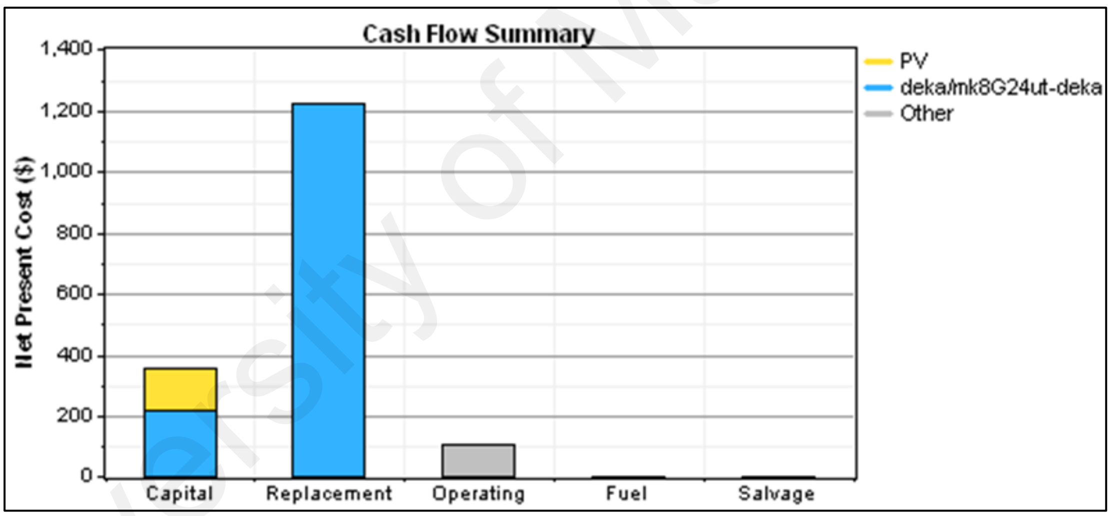

Fig 4.3:20 years projected cash flow summary for selected battery case A

Figure 4.4 shows the monthly average electric production for case A and the power amount of each month. Also figure 4.5 shows the PV output of each month in 24 hours of day.

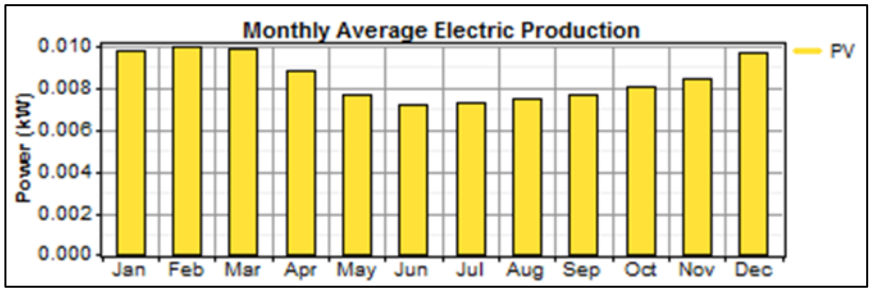

Fig 4.4: Monthly average electric production for case A

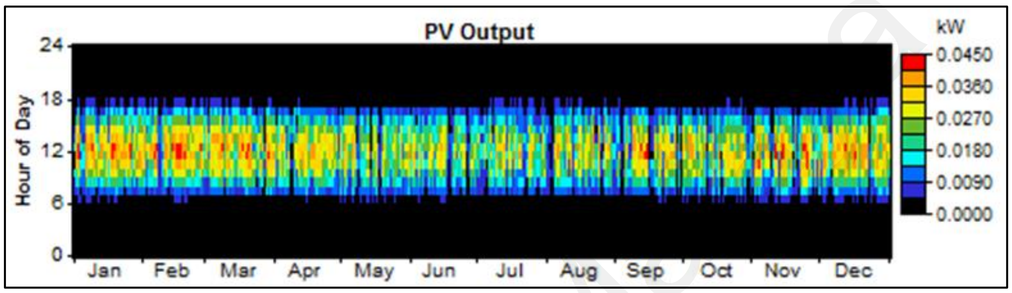

Fig 4.5: daily PV output for case A

Frequency histogram is a graph that uses vertical columns to show frequencies and no gaps between the bars should exist. Figure 4.6 demonstrates the frequency (%) in terms of state of charge (%). Also figure 4.7 shows SOC (%) in terms of monthly statics and figure number 4.8 exhibits battery bank state of charge for each hours of day for case A.

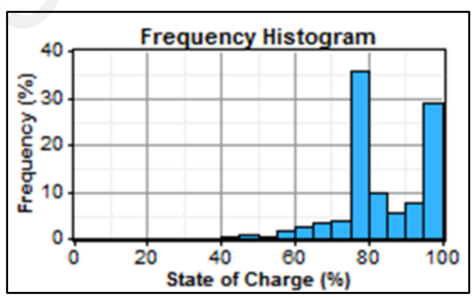

Fig 4.6: Frequency histogram for case A

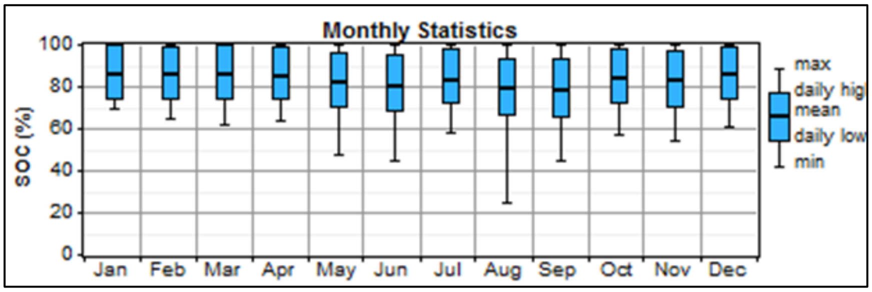

Fig 4.7: Monthly statics for case A

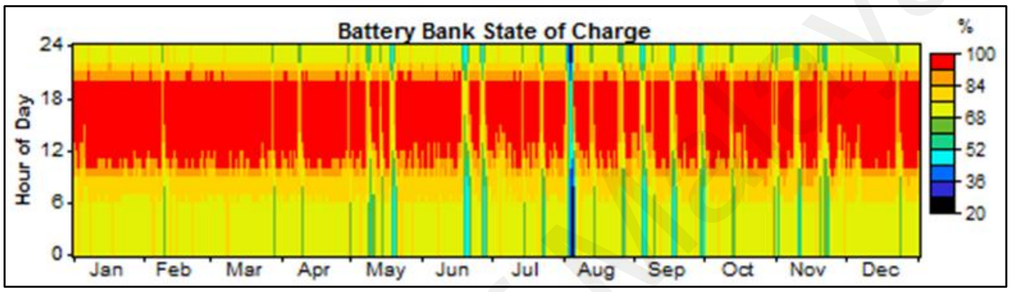

Fig 4.8: battery bank state of charge for case A

Figure 4.9, indicates that for a village of 40 households using 9W appliance for 8 h (CASE A) and residing in a distance more than 0.0424 km far from grid extension, using 40W PV module SHS is more economical.

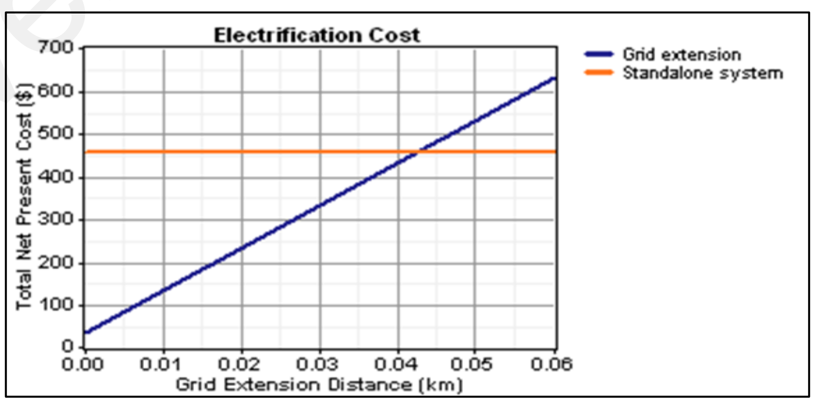

Fig 4.9: Grid extension for case A

Optimization results for case B shows that levelised unit cost of electricity (US$/kWh) is 0.71 from calculation and 0.839 from HOMER (fig 4.10).

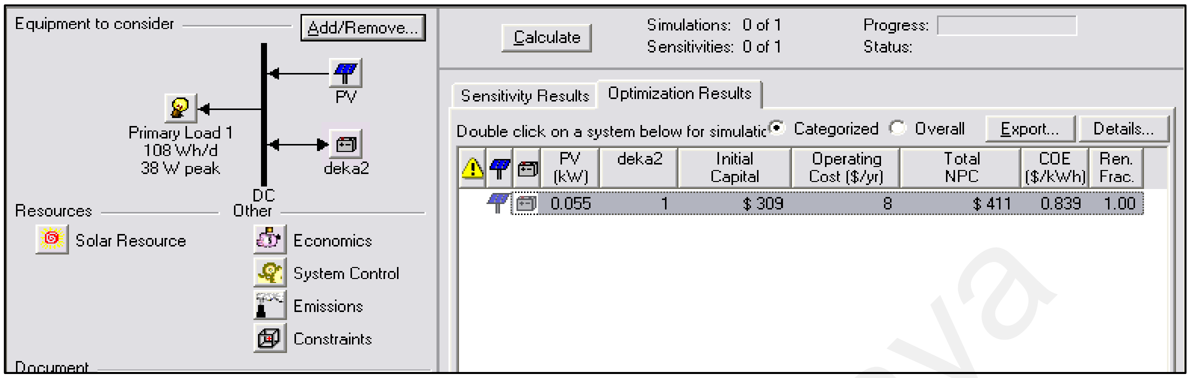

Fig 4.10: Optimization results for case B by HOMER

20 years projected cash flow for selected battery (fig 4.11), cash flow summary (fig 4.12), monthly average electric production (fig 4.13), PV output (fig 4.14), frequency histogram (4.15), monthly statics (fig 4.16) and battery bank state of charge (fig 4.17) are computed for case B.

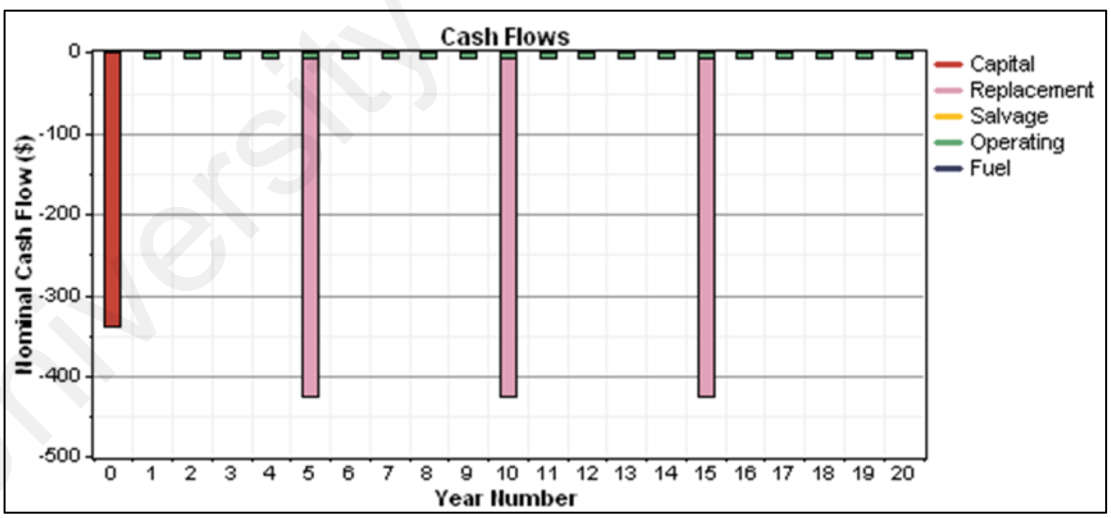

Fig 4.11: 20 years projected cash flow for selected battery case B

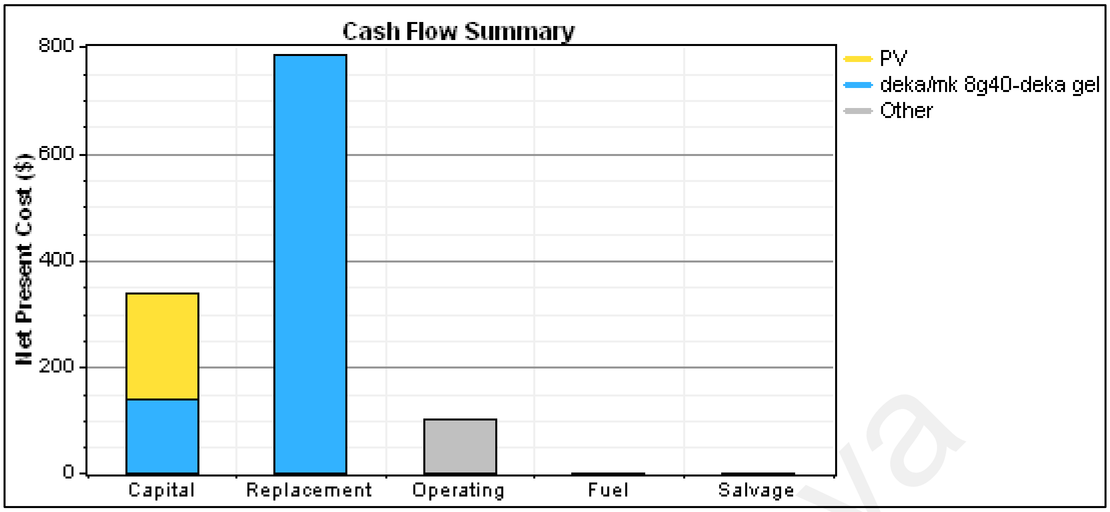

Fig 4.12:20 years projected cash flow summary for selected battery case B

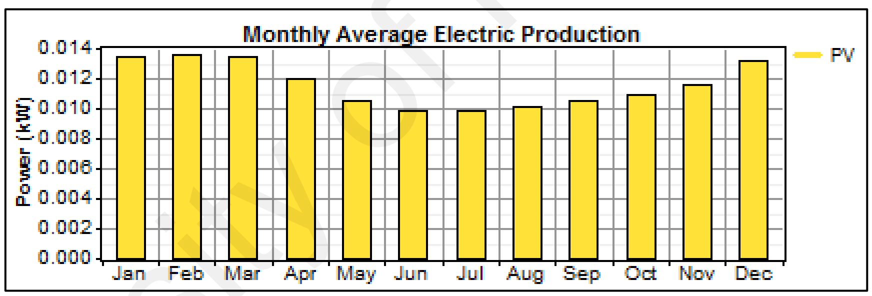

Fig 4.13: Monthly average electric production for case B

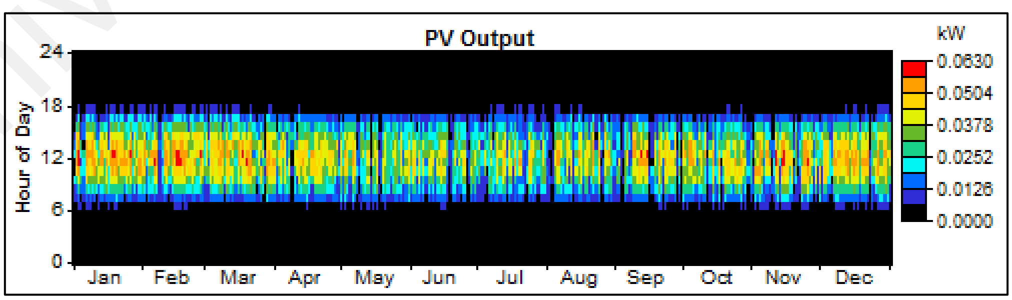

Fig 4.14: daily PV output for case B

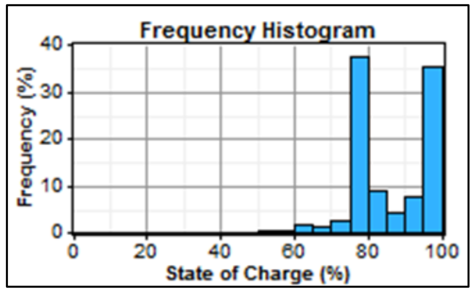

Fig 4.15: Frequency histogram for case B

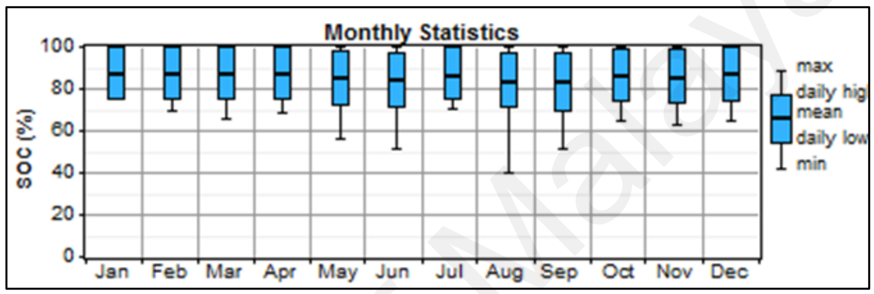

Fig 4.16: Monthly statics for case B

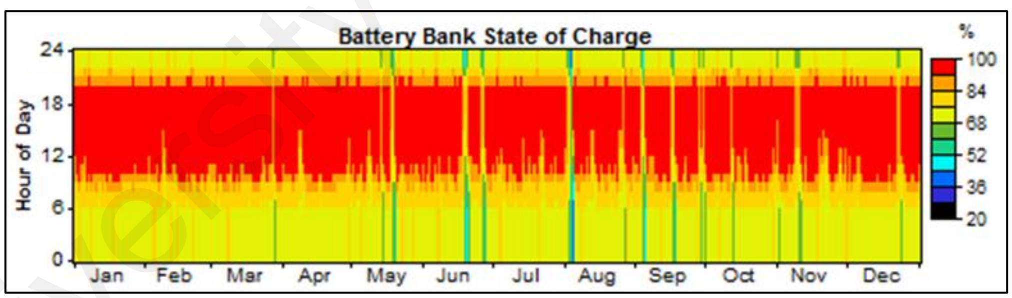

Fig 4.17: battery bank state of charge for case B

Figure 4.18 indicates that for a village of 40 households using 36W appliance for 3 h (CASE B) and residing in a distance more than 0.0393 km far from grid extension, using 55W PV module SHS is more economical.

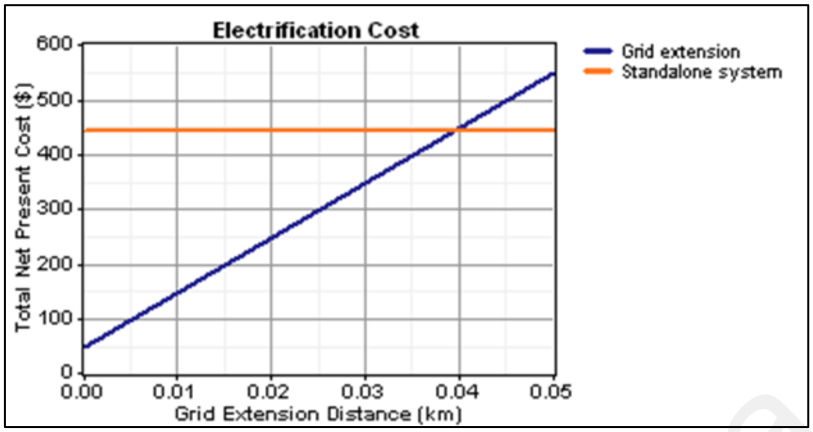

Fig 4.18: Grid extension for case B

Optimization results for case C shows that levelised unit cost of electricity (US$/kWh) is 0.99 from calculation and 0.97 from HOMER (fig 4.19).

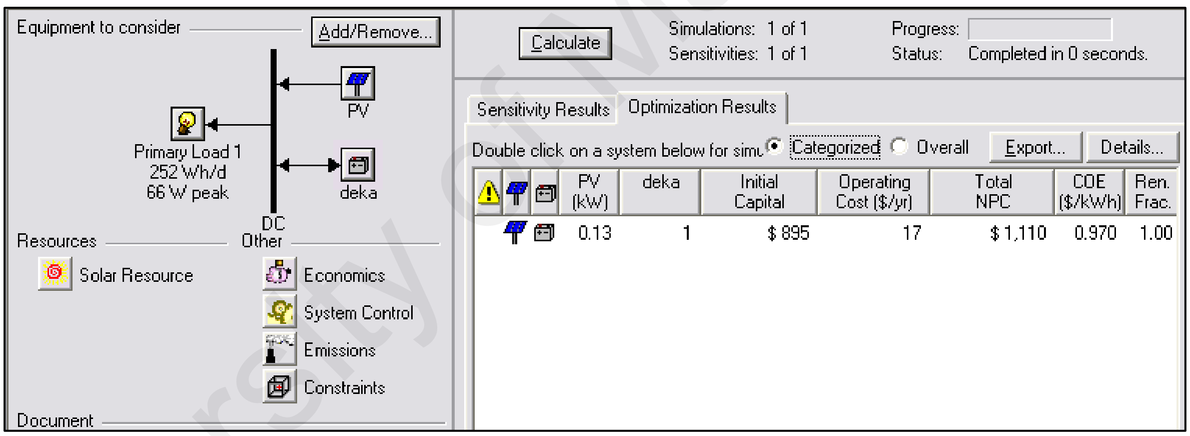

Fig 4.19: Optimization results for case C by HOMER

20 years projected cash flow for selected battery (fig 4.20), cash flow summary (fig 4.21), monthly average electric production (fig 4.22), PV output (fig 4.23), frequency histogram (4.24), monthly statics (fig 4.25) and battery bank state of charge (fig 4.26) are computed for case C.

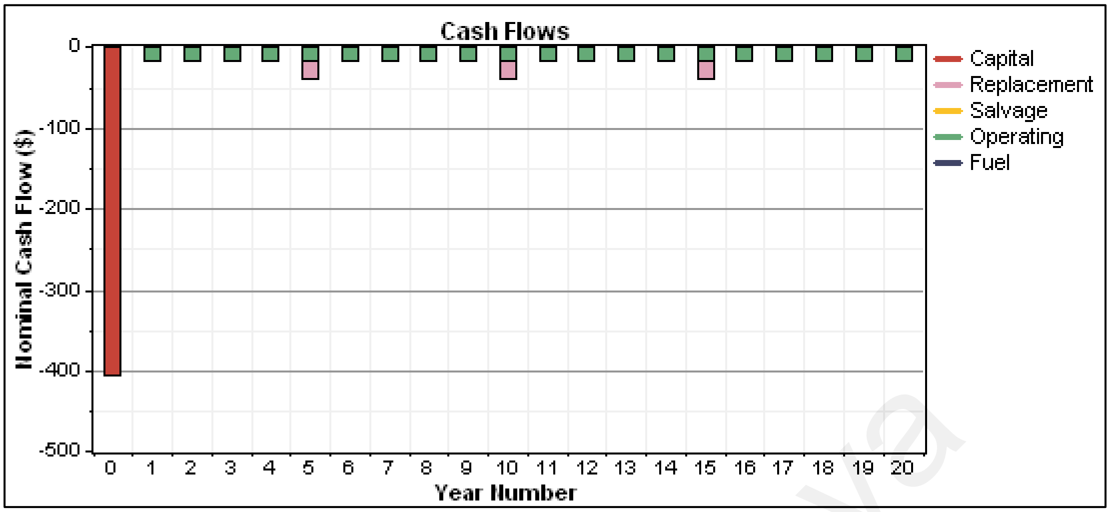

Fig 4.20: 20 years projected cash flow for selected battery case C

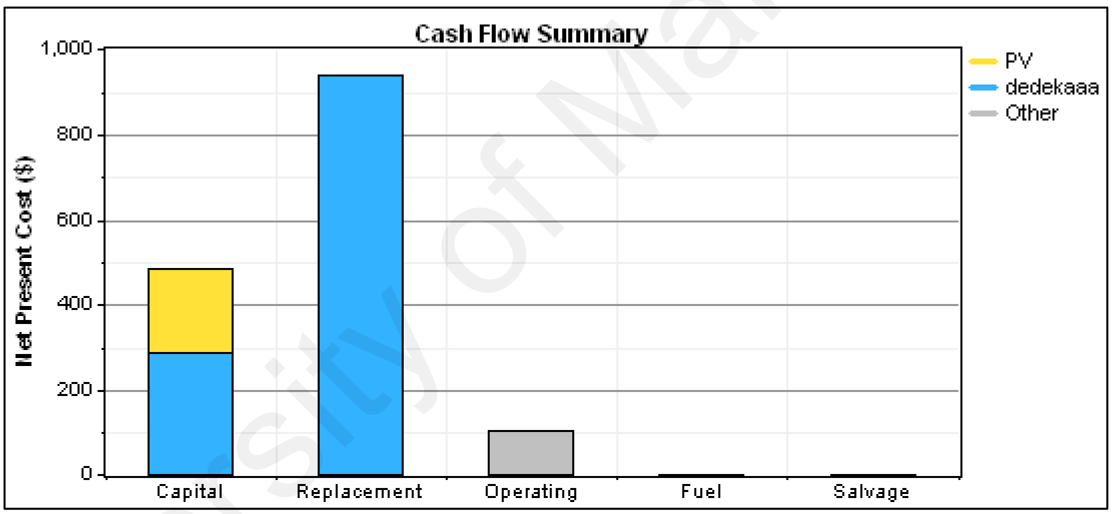

Fig 4.21: 20 years projected cash flow summary for selected battery case C

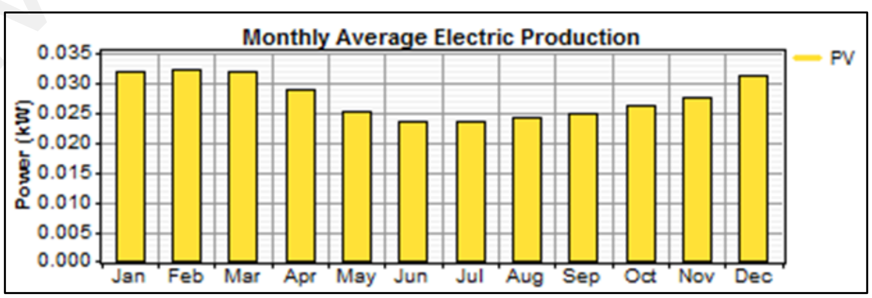

Fig 4.22: Monthly average power production for case C

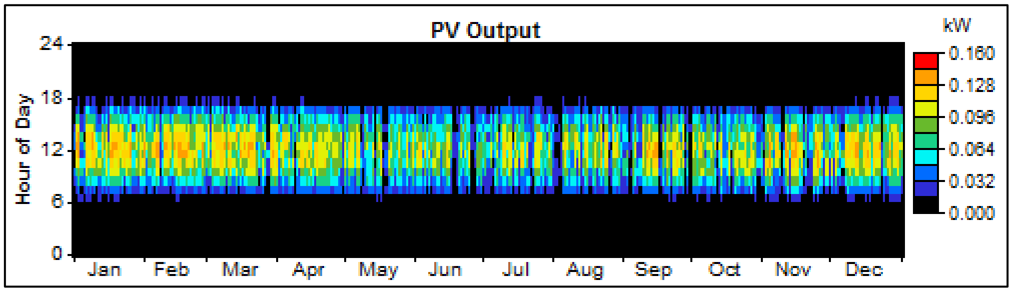

Fig 4.23: daily PV output for case C

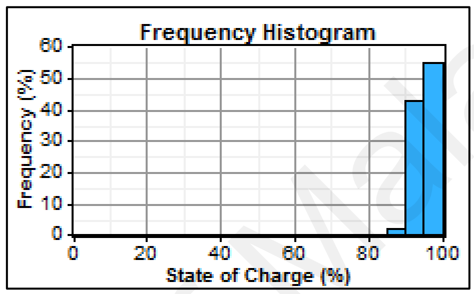

Fig 4.24: Frequency histogram for case C

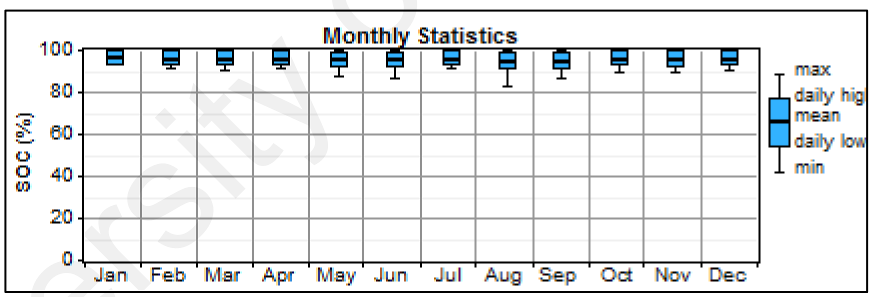

Fig 4.25: Monthly statics for case C

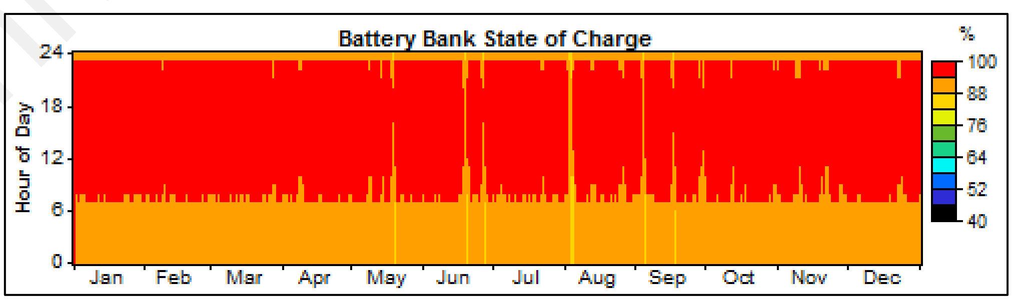

Fig 4.26: battery bank state of charge for case C

Figure 4.27 indicates that for a village of 40 households using 63W appliance for 4 h (CASE C) and residing in a distance more than 0.0786 km far from grid extension, using 2×65W PV module SHS is more economical.

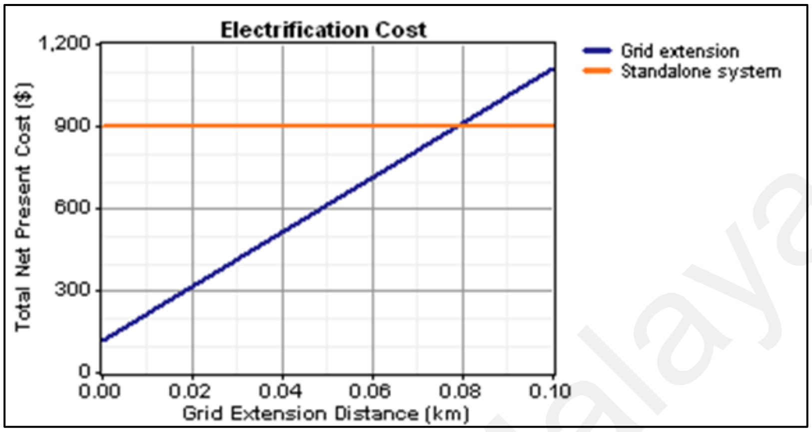

Fig 4.27: Grid extension for case C

Ultimately, comparing the three cases it is obvious in fig 4.18 that in case (B)-the 40 households with using high load electricity (36W for 3 h)-the breakeven point for grid extension occurs at 0.0393km distance (The shortest distance). Therefore, utilizing PV module SHS for case (B) is more economically logical, worthwhile and sustainable.

CHAPTER FIVE: CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

The significant role of electrification toward economic development in countries has always been confirmed. Aside from this important benefit, electrification can lead to improvements public growth as well as remarkable enhancements in the conditions of nature and life. In rural areas in order to achieve a raise in standards of living, health and education as well as growth within local economies, reliable access to electricity seems essential.

Cambodia's population, of which 85% live in rural areas, is indicated to own the 16^{th} lowest income country the world. According to the government policy of enabling 70% of rural households to reach reliable electricity services by 2030, investigation on energy situation in Cambodia and dissemination, usage of solar home system (SHS) seems to be quite necessary.

Solar home systems (SHS) are often used to benefit the rural households that are deprived of connection to electricity grid by providing basic electricity services. It has been shown that the solar home system for small communities far from nation grid is the more economical option than microgrid or extension nation gird. This study presents a techno-economic analysis of solar home system based on calculating annualized life cycle cost (ALCC) for three chosen cases (low, average and high loads of 9W, 36W and 63W respectively). This analysis was carried out for 40 households residing in rural area.

According to obtained results from technical analysis, the best PV available for case A,B and C would be 40Wp, 55Wp and 2×65Wp respectively and most proper battery available are found to be 12V,73.6Ah for case A, 12V,40Ah for case B and 12V,180Ah for case C. For charge controller, case A and B own the similar 5Ah, 12v and for case C 15Ah, 12v would be selected.

From an economic analysis point of view, cases A, B and C showed 74.46, 102.38, and 241.99 (kWh) values for annualized life cycle cost (ALCC). Besides, the levelised unit cost of electricity (LUCE) was calculated to be 1.13, 0.71 and 0.99 (US$./kWh) for the three mentioned case studies.

Using HOMER, results from calculations of technical and economic analysis were rechecked. The results were observed to be in good accordance (near 90% similarity). HOMER gave out the levelised unit cost of electricity (LUCE) for case A,B and C to be 1.3 ,0.839,0.97 (US$./kWh) respectively which shows the concordance with calculation results indicating that case B is the economical one. This result is true if the target is to compare the cases in terms of the lowest price of electricity and to exclude the amount of operating hours.

Other parameters acquired by running HOMER include: 20 years (life time of PV module) projected cash flow for selected battery, cash flow summary, monthly average electric production, PV output, frequency histogram, monthly statics and battery bank state of charge.

A comparison was made between the implementation of SHS and grid extension for the three load options using HOMER. Three values of Breakevn grid extension distance for cases A, B and C were obtained as 0.0424, 0.0393 and 0.0786 km respectively. For hoseholds residing in distances longer than the mentioned values, 40W, 55W and 2×65W PV module SHS seem to be more economical choices. On the other hand, grid extension would be the more feasible option for shorter distances. As the final verdict, case B can be voted as the most economical choice for our studied area terms of the distance from grid extension.

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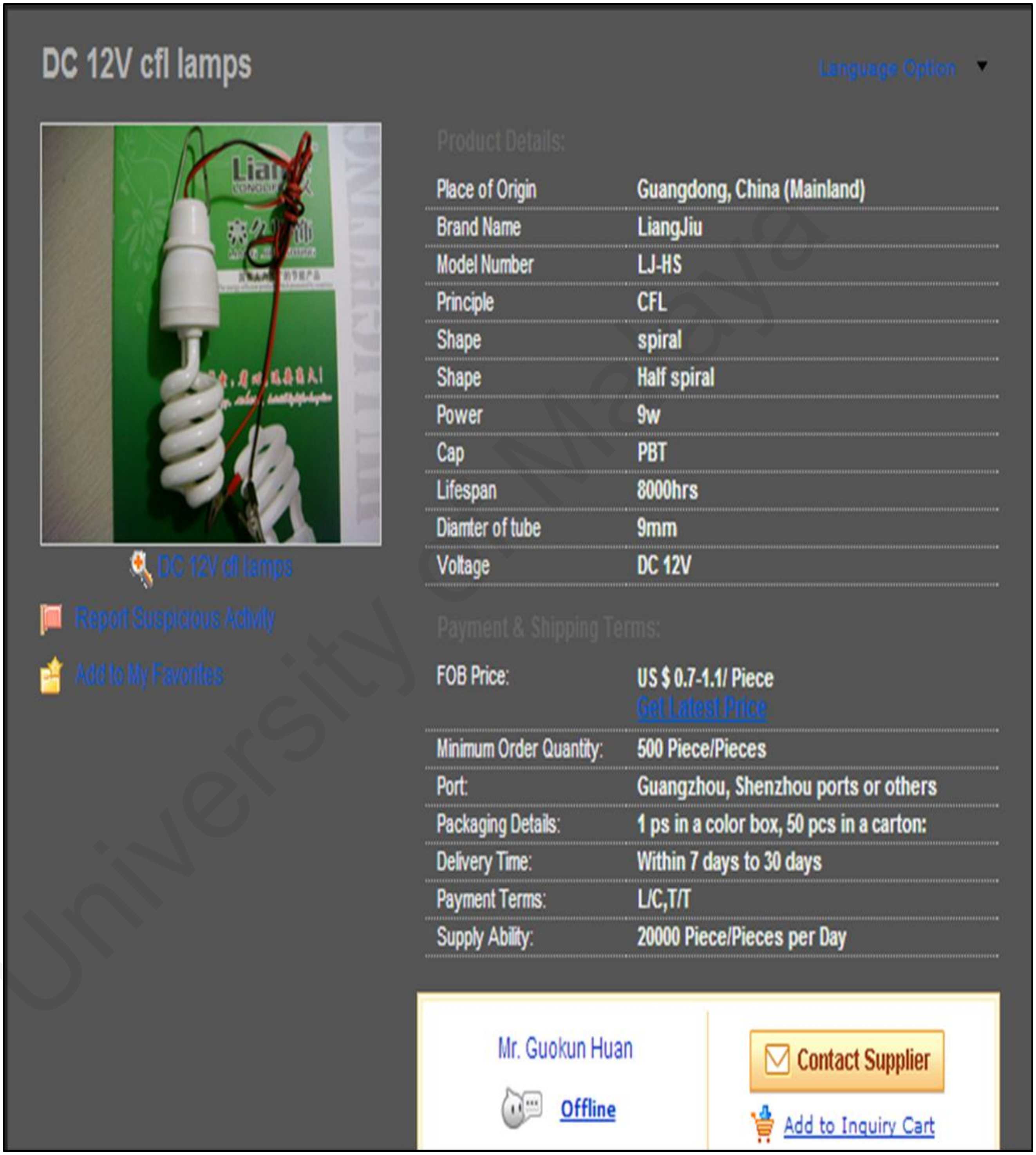
Appendix A

CFL 9W, 12V CATALOGUE



DC 12V cfl lamps

Language Option

Product Details:

Place of Origin	Guangdong, China (Mainland)
Brand Name	LiangJiu
Model Number	LJ-HS
Principle	CFL
Shape	spiral
Shape	Half spiral
Power	9w
Cap	PBT
Lifespan	8000hrs
Diamter of tube	9mm
Voltage	DC 12V

DC 12V cfl lamps

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Payment & Shipping Terms:

FOB Price:	US $ 0.7-1.1/ Piece Get Latest Price
Minimum Order Quantity:	500 Piece/Pieces
Port:	Guangzhou, Shenzhou ports or others
Packaging Details:	1 ps in a color box, 50 pcs in a carton:
Delivery Time:	Within 7 days to 30 days
Payment Terms:	L/C,T/T
Supply Ability:	20000 Piece/Pieces per Day

Mr. Guokun Huan

Offline

Contact Supplier

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Appendix B

40W,12 V SOLAR MODULE CATALOGUE

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Get $5 back on your first Bill Me Later purchase

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- High Power Solar Panels - Over 100 Watts
- MC Interconnect Cables for Solar Electric Panels
- Solar Panel Array Combiners, Breakers and Fuses
- Diodes for Solar Panels
- Grid-Tie System Example Quotations
- RV Solar Electric Systems

Solar Charge Controllers

Solar Panel Mounts & Trackers, RV Mounts

Inverters - Battery Based, Off Grid, RV & Backup

Inverters - Grid Tie for Utility Connected Solar Systems

Pre-Designed Solar Electric Systems and Kits

Outback Power Inverters & System Accessories

Midnite Solar System Installation Products

Deep Cycle Batteries & Accessories

Deep Cycle Battery Chargers & Accessories

Meters: Volt, Amp, Battery Monitors, Shunts

Solar Converters Equipment and Accessories

Solar Water Pumps, DC Pumps, Solar Well Pumps

Electrical - Wire, Fuses, Connectors, Enclosures

DC Lighting:Thin-Lite DC

Home > Solar Electric Panels & Array Combiners > 1 to 100 Watt Solar Electric Panels > Solartech 40 Watt 12 Volt Multicrystalline Solar Module

Solartech 40 Watt 12 Volt Multicrystalline Solar Module

CLICK TO ENLARGE TELL A FRIEND

Item#: SPM040P-XX

Regular Price: $168.00

Our Discounted Price: $136.50

Choose Voltage: 12 Volts

Quantity: 1

ADD TO CART

Availability: In Stock

ITEM DESCRIPTION DETAILS

SPM040P 40 Watt, 12 or 24 Volt Solar Module

Note: This model is available in both 12 and 24 volts DC. The voltage can be selected in the drop-down menu. We stock the 12 volt model and the 24 volt model is available for order.

This 40 watt solar module by Solartech is ideal for charging and maintaining a small battery bank. The module comes standard with MC4 connectors from the junction box. This allows you to easily connect multiple modules in series or parallel. The Morningstar SunGuard 4.5 amp solar charge controller will work with a single 40 watt module. If you need to use two 40 watt modules in parallel (for 12 volt systems), the Morningstar SunSaver 6 amp charge controller will work great.

Specifications:

Max Rated Power (Pmax)	40 Watts
Voltage at Max Power (Vmp)	17.3 Volts
Current at Max Power (Imp)	2.35 Amps
Open Circuit Voltage (Voc)	21.8 Volts
Short Circuit Current (Isc)	2.57 Amps
Max. System Voltage	1,000 Volts DC
Length x Width x Depth (inches)	26.2 x 21.1 x 1.38
Weight of Module	11.01 lbs.
Cable Connector Type	MC4

The 24 Volt model has a maximum power voltage **(Vmp) of 33.9 Volts**, an open circuit voltage **(Voc) of 41.3 Volts**, a maximum power current **(Imp) of 1.2 Amps** and a short circuit current **(Isc) of 1.45 Amps**

YOU MAY ALSO LIKE...

Solartech 45 Watt 12 volt Multicrystalline Solar Module
Price: $184.00
Sale Price: $149.50

Solartech 55 Watt Multicrystalline Solar Module
Price: $208.00
Sale Price: $169.00

Solartech 30 Watt Multicrystalline Solar Module
Price: $144.00
Sale Price: $117.00

55W,12 V SOLAR MODULE CATALOGUE

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- High Power Solar Panels - Over 100 Watts
- MC Interconnect Cables for Solar Electric Panels
- Solar Panel Array Combiners, Breakers and Fuses
- Diodes for Solar Panels
- Grid-Tie System Example Quotations
- RV Solar Electric Systems

Solar Charge Controllers

Solar Panel Mounts & Trackers, RV Mounts

Inverters - Battery Based, Off Grid, RV & Backup

Inverters - Grid Tie for Utility Connected Solar Systems

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Electrical - Wire, Fuses, Connectors, Enclosures

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Wind Generators &

Home > Solar Electric Panels & Array Combiners > 1 to 100 Watt Solar Electric Panels > Solartech 55 Watt Multicrystalline Solar Module

Solartech 55 Watt 12 Volt Solar Module

CLICK TO ENLARGE   TELL A FRIEND

Item#: SPM055P-XX

Regular Price: $208.00

Our Discounted Price: $169.00

Choose Voltage: 12 Volts

Quantity: 1

ADD TO CART

Availability: In Stock

ITEM DESCRIPTION   DETAILS

Solartech SPM055P 55 Watt, 12 Volt Solar Module

Note: This model is available in both 12 and 24 volts DC. The voltage can be selected in the drop-down menu. We stock the 12 volt model and the 24 volt model is available for order.

The Solartech SPM055P solar module is ideal for off-grid battery charging, powering remote communications equipment, small water pumping systems, and residential grid-tie systems. It's constructed using high efficiency multicrystalline cells that are situated below a low iron tempered glass face. The frame is made of light weight, durable anodized 6063-T5 aluminum. This module comes with prefabricated MC4 connectors on the ends of 3 foot positive and negative wires. Its warranty guarantees 90% of the rated output after 12 years and 80% after 25 years. If you will only be using one of these modules, we recommend the Morningstar SunSaver 6 Amp solar charge controller. If you need extra wire length, the MC4 extender cables can be used. If you are unsure about your setup and need some advice, please email us or call and speak to one of our sales staff. We will be more than happy to help you design your system.

Specifications for Solartech SPM055P Solar Module

Max Rated Power (Pmax)	55 Watts
Voltage at Max Power (Vmp)	18.2
Current at Max Power (Imp)	3.10 Amps
Open Circuit Voltage (Voc)	22.1
Short Circuit Current (Isc)	3.31 Amps
Module Efficiency	13.2%
Max. System Voltage	1000 VDC
Length x Width x Depth (inches)	25.7 x 25.2 x 1.38
Weight of Panel (Pounds)	13.0
Connector Cable Type	MC4 Latching Cables (3 feet)

YOU MAY ALSO LIKE...

8 Foot MC4 Extender Cable Male/Female
Price: $17.80

MidNite Solar MNBCM Battery Capacity Meter
Price: $69.00
Sale Price: $49.34

SunSaver 6 Amp 12 Volt Solar Charge Controller
Price: $52.00
Sale Price: $39.00

Solartech 85 Watt Multicrystalline Solar Module
Price: $296.00

130W,12 V SOLAR MODULE CATALOGUE

SHOP BY CATEGORY

Solar Electric Panels & Array Combiners

- 1 to 100 Watt Solar Electric Panels
- High Power Solar Panels - Over 100 Watts
- MC Interconnect Cables for Solar Electric Panels
- Solar Panel Array Combiners, Breakers and Fuses
- Diodes for Solar Panels
- Grid-Tie System Example Quotations
- RV Solar Electric Systems

Solar Charge Controllers

Solar Panel Mounts & Trackers, RV Mounts

Inverters - Battery Based, Off Grid, RV & Backup

Inverters - Grid Tie for Utility Connected Solar Systems

Pre-Designed Solar Electric Systems and Kits

Outback Power Inverters & System Accessories

Midnite Solar System Installation Products

Deep Cycle Batteries & Accessories

Deep Cycle Battery Chargers & Accessories

Meters: Volt, Amp, Battery Monitors, Shunts

Solar Converters Equipment and Accessories

Solar Water Pumps, DC Pumps, Solar Well Pumps

Electrical - Wire, Fuses, Connectors, Enclosures

DC Lighting:Thin-Lite DC Lights & Iota DC Ballasts

Home > Solar Electric Panels & Array Combiners > 1 to 100 Watt Solar Electric Panels > Power Up 65 Watt Multicrystalline 12 volt Solar Module

Power Up 65 Watt Multicrystalline 12 volt Solar Module

Item#: BSP65-12

Our Price: $200.00

Quantity: 1

ADD TO CART

Availability: In Stock

CLICK TO ENLARGE ▸TELL A FRIEND

ITEM DESCRIPTION DETAILS

Power Up 65 Watt 12 Volt Solar Module

The BSP65-12 has a junction box with connection terminals. The anodized aluminum frame provides for easy mounting offers full protection for years of continued charging.

Specifications:

Electrical Specifications

Maximum Power (Pmax)	65 W
Voltage at Pmax (Vmp)	17.8 V
Current at Pmax (Imp)	3.57A
Short-Circuit Current (Isc)	3.92A
Open-Circuit Voltage (Voc)	21.9V

Physical Specifications

Dimensions	39.8" x 20.1" x 1.38"
Weight	15 lbs

10 year warranty

YOU MAY ALSO LIKE...

Solartech 85 Watt Multicrystalline Solar Module
Price: $296.00
Sale Price: $240.50

Solartech 55 Watt Multicrystalline Solar Module
Price: $208.00
Sale Price: $169.00

ET Solar 45 Watt 12 volt Monocrystalline Solar Module
Price: $135.00

Appendix C

12V,73.6 AH SOLAR BATTERY


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    - » Deka MK Batteries
    - » Surrette Batteries
  - » Vents
- » Charge Controllers
- » Electrical & Safety Supplies
- » Grid Tie Kits
- » Inverters & Accessories
- » Mounts & Trackers
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Products > Batteries & Enclosures > Solar Batteries > Deka MK Batteries >

Deka/MK 8G24UT-DEKA Gel, 12 volt 73.6 AH

Item Code: **815**

Installers call for Wholesale pricing

Your Price: **$217.07**

Quantity: 1

ADD TO CART

Description | Data Sheets | Shipping Info | Reviews

Deka/MK Battery 8G24UT-DEKA Sealed Gel Battery, 12 volt 73.6 AH

Can gel cells be installed in sealed battery boxes?

NO! Never install any type of battery in a completely sealed container. Although the normal gasses (oxygen and hydrogen) produced in a gel cell battery will be recombined as described above, and not escape, oxygen and hydrogen will escape from the battery in overcharge condition (as is typical of any type of battery).

For safety's sake, these potentially explosive gasses must be allowed to vent to the atmosphere and must never be trapped in a hermetically sealed battery box or tightly enclosed space!

Nominal Voltage (V): 12 volts
Capacity at C/100: 84.5 AH
Plate Alloy: Lead Calcium
Posts: Forged terminals & bushings
Container/Cover: Polypropylene
Operating Temperature: -76°F (-60°C) to 140°F (60°C)
Charge Voltage @ 68°F (20°C)
Cycle: 2.30 to 2.35 VPC
Float: 2.25 to 2.30 VPC
Vent: Self-sealing (2 PSI operation)
Electrolyte: Sulfuric acid thixotropic gel
Resistance: 4.0 Milliohms (full charge)
Terminal: T881

Rated non-spillable by ICAO, IATA and DOT
Approved by CEC

12V,40 AH SOLAR BATTERY

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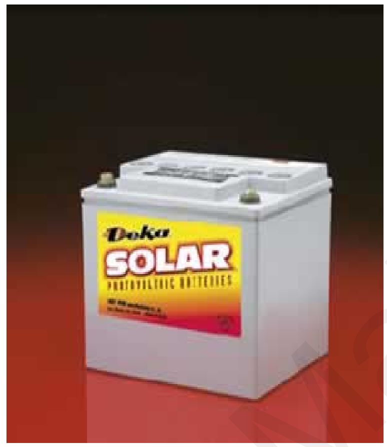
Products > Batteries & Enclosures > Solar Batteries > Deka MK Batteries >



Deka/MK 8G40-DEKA Gel, 12 volt 40 AH

Item Code: **3811**

Installers call for Wholesale pricing

Your Price: **$139.65**

Quantity: 1

ADD TO CART

Can gel cells be installed in sealed battery boxes?

NO! Never install any type of battery in a completely sealed container. Although the normal gasses (oxygen and hydrogen) produced in a gel cell battery will be recombined as described above, and not escape, oxygen and hydrogen will escape from the battery in overcharge condition (as is typical of any type of battery).

For safety's sake, these potentially explosive gasses must be allowed to vent to the atmosphere and must never be trapped in a hermetically sealed battery box or tightly enclosed space!

Specifications

- Nominal Voltage: 12 volts
- Capacity at C/100: 48 AH
- Plate Alloy: Lead Calcium
- Posts: Forged terminals & bushings
- Container/Cover: Polypropylene
- Operating Temperature Range: -76°F to 140°F (-60°C to 60°C)
- Charge Voltage at 68°F (20°C)
- Cycle: 2.30 to 2.35 VPC
- Float: 2.25 to 2.30 VPC
- Vent: Self Sealing
- Electrolyte: Sulfuric acid thixotropic gel
- Terminal: C (Insert w/ 1/4" - 20 round hole)

Rated non-spillable by ICAO, IATA, and DOT

Made in the USA by East Penn Manufacturing

Weight: 32 lbs. (14.5 kg)

Dimensions LxWxH: 7.76" x 6.62" x 6.87" (197 x 168 x 174 mm)

12V,180 AH SOLAR BATTERY

Appendix D

Charge controller catalog for 5A and 15A

CINCO 吉博电子

NINGBO

GEEBO ELECTRONICS TECHNOLOGY CO.,LTD

Tel:(86) 574 26268605 26268608
Fax:(86)574 26268609 26268608
Email: Sales@Cinco-Solar.Com
Http:www.solars-panel.com

Solar Charge Controller Price List

Item No	Description of The Goods	MOQ	Unit Price
MPPT Solar Controller Tracer series			
Tracer-1206RN	60V input MPPT Controller 10A 12V/24V auto Switch	10pcs	$42.00/pc
Tracer-1210RN	100V input MPPT Controller 10A 12V/24V auto Switch	10pcs	$44.00/pc
Tracer-1215RN	150V input MPPT Controller 10A 12V/24V auto Switch	10pcs	$46.00/pc
Tracer-2210RN	100V input MPPT Controller 20A 12V/24V auto Switch	10pcs	$72.50/pc
Tracer-2215RN	150V input MPPT Controller 20A 12V/24V auto Switch	10pcs	$77.00/pc
Tracer-3215RN	150V input MPPT Controller 30A 12V/24V auto Switch	10pcs	$108.00/pc
MPPT Solar Controller E-Tracer series with LCD and communication			
eTracer-ET2415	150V input MPPT Controller 20A 12V/24/36/48V auto Switch	10pcs	$230.00/pc
eTracer-ET3415	150V input MPPT Controller 30A 12V/24/36/48V auto Switch	10pcs	$255.00/pc
eTracer-ET4415	150V input MPPT Controller 45A 12V/24/36/48V auto Switch	10pcs	$285.00/pc
eTracer-ET6415	150V input MPPT Controller 60A 12V/24/36/48V auto Switch	10pcs	$330.00/pc
PWM Solar Controller LandStar series			
LS1024	PWM 10A 12V/24V auto Switch	50pcs	$13.50/pc
LS1524	PWM 15A 12V/24V auto Switch	50pcs	$19.00/pc

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GEEBO ELECTRONICS TECHNOLOGY CO.,LTD

Tel:(86) 574 26268605 26268608
Fax:(86)574 26268609 26268608
Email: Sales@Cinco-Solar.Com
Http:www.solars-panel.com

Solar Charge Controller Price List

Item No	Description of The Goods	MOQ	Unit Price
PWM Solar Controller ViewStar series			
VS1024N	PWM 10A 12V/24V auto Switch LCD display;Adjustable	10pcs	$38.00/pc
VS2024N	PWM 20A 12V/24V auto Switch LCD display;Adjustable	10pcs	$52.00/pc
VS3024N	PWM 30A 12V/24V auto Switch LCD display;Adjustable	10pcs	$78.00/pc
VS4024N	PWM 40A 12V/24V auto Switch LCD display;Adjustable	10pcs	$115.00/pc
VS5024N	PWM 50A 12V/24V auto Switch LCD display;Adjustable	10pcs	$118.00/pc
VS6024N	PWM 60A 12V/24V auto Switch LCD display;Adjustable	10pcs	$125.00/pc
VS2048N	PWM 20A 12V/24V/48V auto Switch LCD display;Adjustable	10pcs	$80.00/pc
VS3048N	PWM 30A 12V/24V/48V auto Switch LCD display;Adjustable	10pcs	$120.00/pc
VS4048N	PWM 40A 12V/24V/48V auto Switch LCD display;Adjustable	10pcs	$130.00/pc
VS5048N	PWM 50A 12V/24V/48V auto Switch LCD display;Adjustable	10pcs	$145.00/pc
VS6048N	PWM 60A 12V/24V/48V auto Switch LCD display;Adjustable	10pcs	$155.00/pc
PWM Solar Controller CINCO series			
CNCD-3A	Solar Controller 3Amps 12V/24V auto Switch	50pcs	$11.50/pc
CNCD-5A	Solar Controller 5Amps 12V/24V auto Switch	50pcs	$12.50/pc
CNCD-10A	Solar Controller 10Amps 12V/24V auto Switch	50pcs	$13.50/pc