MSc in Sustainable

Economic Feasibility of PV Net Metering for Maseru South West (MASOWE) Residential Sector

By

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Submitted in Fulfilment of the Requirement for the Degree of

Master of Science in Sustainable Energy

in the

Faculty of Science and Technology

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Submission Date: April 2024

DECLARATION

I, Mathatela Ntsatsi (199900573), declare that the ECONOMIC FEASIBILITY OF SOLAR PV NET METERING FOR MASERU SOUTH WEST (MASOWE) RESIDENTIAL SECTOR are my own work and that all the sources that I cited have been indicated and acknowledged by means of complete references.

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ABSTRACT

Net metering is a well-known mechanism that credits the prosumer for the surplus energy transferred from the solar power self-production of their consumption to the main utility grid. Therefore, this study investigates the technical and economic feasibility of net metering in Lesotho to alleviate the energy supply shortage and meet the demand. Electricity supply of 77 MW (hydro, solar and generator generation) remains a significant challenge for the government of Lesotho in fulfilling its top priority to meet the demand of 170 MW. For this reason, it is important to consider strategies, like net metering, to promote renewable energy to meet the energy demand.

The study performed the technical and financial analysis for the Maseru South West (MASOWE) residential Net Metering in Lesotho to get a clear picture of technical and economic cost-benefit analysis to inform the policy direction. The study reveals that net metering is viable for the MASOWE residential sector for implementation. The type of net metering recommended for MASOWE households is energy credit net metering under restricted limitations and standards. This type of net metering provides net balance resolution where prosumer compensation is through the reduction of electricity billing. The five scenarios that have been investigated show that solar Photovoltaic (PV) hybrid systems with doubledsized solar power are most viable for net metering. The system consisting of a 2 kW solar PV and a 2 kW inverter seems to be the most promising configuration. The system load factor is 34%; the Net Present Cost (NPC) is $3,838.88; the initial capital cost is $1,553.00; the operation and maintenance cost is $96.09/yr; and the levelised cost of energy (LCOE) is $0.0282/kWh. In Lesotho, this LCOE is less than the $0.13/kWh of the Grid tariff. Again, $0.0282/kWh LCOE is far less than the $0.1/kWh average South African Development Community (SADC) LCOE projection of 2019. In addition, the system is economically viable and attractive, with an Internal Rate of Return (IRR) of 27%, a Return on Investment of 22%, and the shortest payback period of slightly over 3.7 years. The system's avoided energy cost of $0.0102/kWh makes net metering more attractive for households. However, there is a need to encourage and facilitate the participation of female entrepreneurs and experts in the net metering system.

ACKNOWLEDGEMENT

First and foremost, let me thank and praise the Almighty God for the blessings throughout my successful research study.

I would like to express my deep and sincere gratitude to my research supervisors, Prof. Molibeli Taele and Mr. Moruti Kao, for their excellent guidance and supervision of the research. Their dynamism, vision, and motivation have inspired me. Amongst other elements of research, their guidance on the relevant methodology for this study was remarkable. Therefore, working and studying under their guidance was a great privilege and honour.

Let me also thank Prof. Thamae and Mr Mokeke for their input on the development and implementation of models used in this study. Through these models, the results came out concrete, thus completing the feasibility and possibility of the study. Indeed, I am incredibly grateful for what they offered me. My thanks also extend to their friendship, empathy, and sense of humour.

I would also like to thank the Faculty of Science and Technology for giving me this opportunity to carry out the study.

My heartfelt gratitude also extends to my wife and my family for their acceptance and patience while always busy doing this study. They allowed me to have sleepless nights during my discussions and research journey. I am grateful because of their love, prayers and care. They have sacrificed for my education, which prepares my future. Their continuous support is overwhelming.

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ACRONYMS AND ABBREVIATIONS

i.	DOE	Department of Energy
ii.	EDM	Electricidade de Mozambique
iii.	ESCOM	Electricity Supply Commission
iv.	IRR	Internal Rate of Return
v.	LCC	Life Cycle Cost

vi.	LCOE	Levelised Cost of Energy
vii.	LEC	Lesotho Electricity Company
viii.	FIT	Feed in Tariff
ix.	GHG	Green House Gases
x.	GWh	Gigawatt hours
xi.	MASOWE	Maseru South West
xii.	MW	Megawatts hours
xiii.	NASA	National Aeronautics and Space Administration
xiv.	NPC	Net Present Cost
xv.	NPV	Net Present Value
xvi.	REC	Renewable Energy Credits
xvii.	RES-E	Renewable Energy Sources for power generation
xviii.	ROI	Return on Invest
xix.	SADC	South African Development Community
xx.	SDG	Sustainable Development Goals

CHAPTER ONE

INTRODUCTION

1.0 Introduction

The global demand for development and a better standard of living initiated the development of international treaties, such as the Sustainable Development Goals (SDGs) and Environmental Treaties [1], [2], [3]. These goals, which include SDG 7 on the use of accessible, reliable and affordable energy, have promoted energy access to balance the demand and supply of electricity [4]. Over and above that, environmental treaties, such as the Kyoto Protocol, have urged countries to promote clean energy to reduce greenhouse gases; this is for the mitigation and adaptation to climate change [5]. Lesotho has adopted these treaties through the development of the Energy Policy (2015-2025) and the Climate Change Policy (2017-2027) [6, 7]. The Lesotho energy and climate change policies promote clean and, renewable energy, such as solar, wind and hydropower. The Energy Policy also includes strategies to introduce the net metering system to encourage the adoption of renewable energy technologies [7].

Solar photovoltaic (PV) systems for residential power generation constructed by customers for their grid-connected electricity generation systems attract many families because of their good economies of scale [8]. The development of this new technology has decreased the cost of PV power generation. As a result, households have been encouraged to adopt home solar power generation systems. The PV systems' low cost and attractiveness give the households an advantage to use mechanisms like feed-in tariffs (FIT), net metering and net purchase, as well as the sale of electricity generated by residential systems (PV-generated electricity) [8]. However, in Lesotho, the demand for electricity production has caused an enormous problem for development and economic growth. Therefore, it is advantageous for Lesotho to adopt these new renewable technologies, like solar PV power systems to meet the demand to boost the country's growth and private sector contribution.

Lesotho has an installed electricity capacity of 77 MW, 95% of which is from hydropower, less than 1% from solar and 5% from other energy sources by 2022 [9]. The peak demand shown in Figure 1 for electricity in Lesotho is 172.15 MW, which was reached in 2022 [10]. This peak demand is far higher than 77 MW of power generation, making the deficit of 95.15 MW, which is compensated by the importation of electricity from South Africa and Mozambique. The Electricity energy production for the year 2020/2021 shown in Figure 2 indicates that the 'Muela Power station was 442.02 GWh, while Electricidade de Mozambique and Eskom in

South Africa exported 99.39 GWh and 32.37 GWh, respectively, to meet the 172.15 MW peak demand. As a result, there should be more options for power generation to reduce 131.76 GWh of electricity imports from the neighbouring countries to boost the economy.

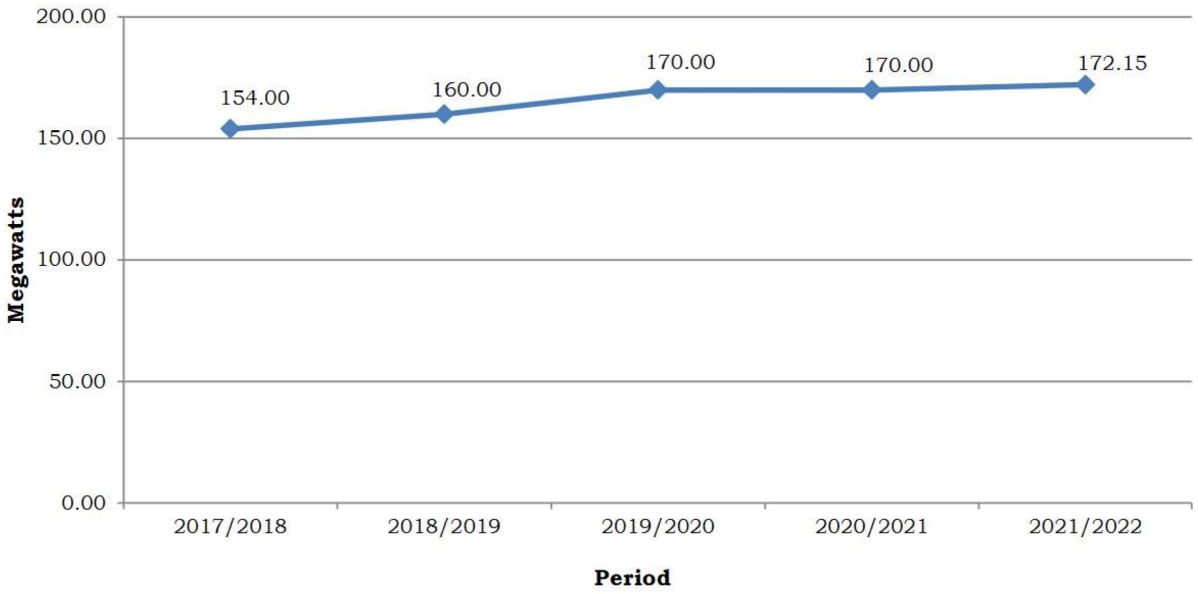


Figure 1: Yearly peak demand (2016 -2021) [10]

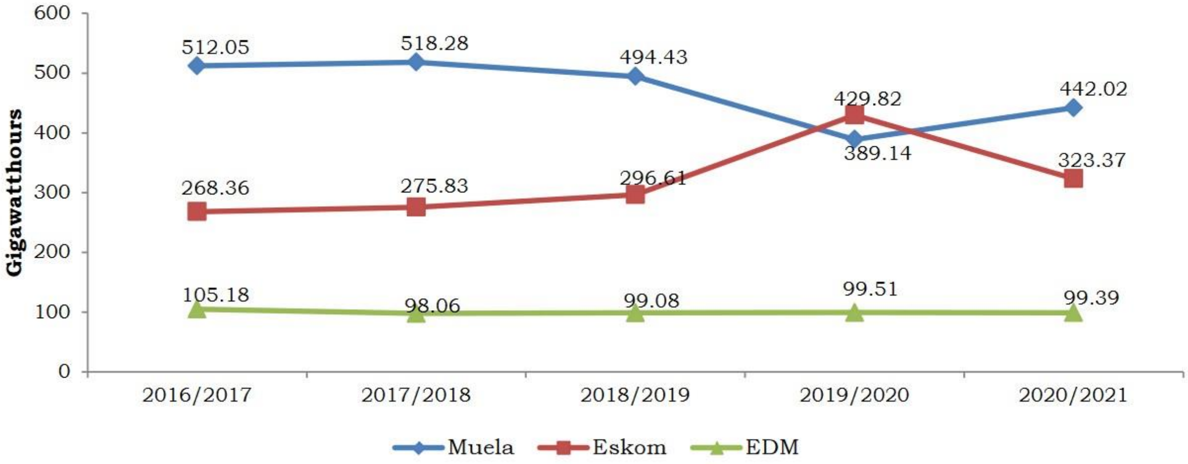


Figure 2: Electricity purchased by IEC (GWh) Source [10]

The Lesotho electricity tariff rates have two domestic tariff classifications: the lifeline block and the standard domestic tariffs [11]. The domestic energy charges for Lesotho are M1.7450/kWh, whereas lifeline domestic are at M0.8511/kWh, which entails both the electricity charges and levies [11]. The Lesotho electricity prices of M1.7450/kWh ($0.130/kWh) for households and M0.2928/kWh ($0.0163/kWh) for businesses are less than the average world's electricity prices of $0.178/kWh for households and $0.186/kWh for the businesses [12]. Therefore, based on this Lesotho household electricity prices, studies are required to find the viability of residential sector net metering and provide affordable energy prices.

1.1 Net Metering

Net metering is the mechanism that credits utility customers for the amount of electricity customers generate and adds to the electricity grid as a partial or complete offset to their monthly consumption [13]. It is the mechanism guided by the energy policies of the host country to encourage individual householders to adopt renewable energy production to reduce the energy demand in an environmentally friendly way. It is the customer’s investment to reduce or eliminate the portion of electricity bills charged [14]. Roux and Shanker define net metering as the obligation under the contract between the energy distributor and the customer who generates their electricity [15]. It is the balance between the energy provided to the grid against the power received from the grid. An individual producer can produce electricity daily and transmit it to the primary grid. This means that the customer gets electricity back from the primary grid during the night when the solar panels do not receive radiation for power production. If the excess amount of electricity is added to the grid, but not consumed by the customer during the night, the utility company has to compensate the customer. Alternatively, if the customer uses excess to what they produce, then they have to pay the utility company. Moreover, Figure 3 represents the net metering process where the solar PV panels get solar radiation from 8 am to 8 pm, and Region 1 is the direct solar PV consumption to load by the consumer [16]. Region 2 shows excess PV production, while Region 3 shows consumption during the night. Since Region 3 is the grid consumption, its billing is compensated by the excess solar PV production of energy reflected by Region 2 during the day.

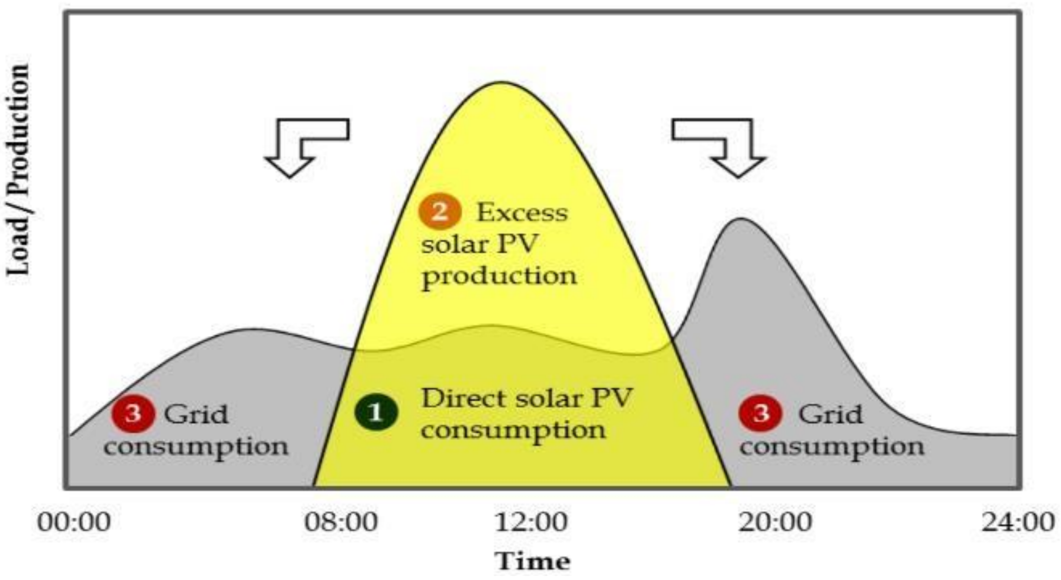


Figure 3: Net Metering [16]

Other countries, such as Namibia, have already developed and enforced net metering policies to increase generation capacity and regulate illegal systems [15]. In contrast, India's net metering policy was meant to boost rooftop solar development. Roux and Shanker have further shown that the Philippines enacted a net metering policy to increase the renewable energy share in the energy mix and reduce the amount of electricity imported [15].

1.2 Problem Statement

According to several research studies, the electricity demand remains a significant challenge for the residential sector in Lesotho [17], [18], [19], [20], [21]. This electricity demand is reflected by more than 50% of the electricity imported from South Africa and Mozambique [22].

Several solutions to this problem, such as the increase in electricity generation and the reduction of demand through energy efficient methods, energy storage and promotion of renewable energy, have been identified as options to solve the lack of energy supply to meet the demand guided by the Lesotho Energy Policy (2015-2025) [22]. The Energy Policy also highlights the need for a net metering scheme to reduce the electricity demand.

This study, therefore, assesses the economic implications and viability of net metering for the

MASOWE residential sector. The assessment also seeks to find the financial viability of the current billing process against the potential billing processes under the net metering system. Furthermore, the study also looks into the potential policy direction for the Lesotho Energy Policy on implementing net metering.

1.3 Research Question and Objectives

1.3.1 Research Question

The inspiration for this study is to provide possible solutions to the issue of energy supply to satisfy the electricity demand for the Lesotho residential sector. As a result, the study responds to the following question:

a) What is the economic feasibility of MASOWE residential sector rooftop solar PV net metering?

1.3.2 Research Objectives

The study seeks to achieve the following objectives:

a) To perform on-grid optimum solar PV technical performance analysis
b) To perform the optimum solar PV net metering analysis
c) To perform the cost and benefit analysis of net metering
d) To assess the economic viability of net metering to the Lesotho residential sector
e) To analyse the avoided cost of energy through a net metering system
f) To perform net metering policy analysis

1.4 Justification

The study intends to assist the government of Lesotho in implementing strategic plans to reduce the energy demand of the residential sector. It provides options to execute the Lesotho Energy Policy on the net metering strategy to alleviate the energy demand; this strategy promotes renewable energy and environmental protection.

The net metering policy is essential for promoting the use of renewable energy [23]. The promotion of renewable energy is the direct reduction of greenhouse gas (GHG) emissions as it assists households to reduce and avoid the use of fossil fuels. It is environmentally friendly and has zero global warming potential. Moreover, this reduction of emissions is a mitigation option to curb the adverse effects of climate change. Zhang and Wang stated that globally, 144 countries' policies, including net metering policies, provide policy direction and incentives to reach the GHG emissions reduction target of 80.5% and impose taxes up to 72.5% [23]. The American net metering and tendering policy reflects an excellent achievement that has provided a significant emission reduction target [24]. This process of renewable energy promotion makes Lesotho compliant with international treaties, such as the Kyoto Protocol and the Paris Agreement, to which it is a signatory.

Renewable energy power generation assists in developing the country and its business sector [25]. Thus, the Net Metering policy and its implementation assist in reducing electricity bills and battery storage costs, reducing the electricity grid pressure and encouraging the promotion of renewable energy.

Further, the study provides solutions for balancing energy demand and supply. Some countries, such as Namibia have used net metering to meet the energy demand and supply economically [26]. Additionally, the potential policy directions of this study are anticipated to assist in reducing the high financial cost of imported electricity due to the reduced cost of electricity generation through net metering.

1.5 The Organisation of the Dissertation

This dissertation has five chapters, which provide guidance to this study, afford the principles of net metering, perform the analysis and provide its economic feasibility for MASOWE. The first chapter introduces the net metering concept and provides the local and international status of the net metering system. It also presents the research question, objective and justification.

The second chapter provides a literature review on the net metering systems. It presents the net metering definition, benefits, policy classification, and the review of solar systems costs.

As for the third chapter, it discusses methodologies that have been adopted from previous studies. It is in this chapter that the procedures to be followed for the analysis of net metering for the MASOWE residential sector were also explained. The guidance in the methodologies includes the development of MASOWE load profile and HOMER modelling, together with technical and economic analysis procedures that could lead to viable economic indicators to conclude on net metering. Chapter four provides the simulation results and analyses, while Chapter five offers conclusions and recommendations for the future net metering development for MASOWE households.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The chapter provides a literature review on net metering policies, recommendations, and conclusions achieved. The net metering definition and review of the related policies for different countries to allow understanding of the net metering policy designs and decisions are covered in this chapter. The load profile development and equations under the literature review are captured to inform the methodology to be adapted.

2.1 Definition of Net Metering

Net metering is the electricity billing mechanism that permits the consumer to offset or reduce the electricity bill charges through self-electricity production from renewable energy sources for power generation (RES-E) plants [13]. Net metering uses a meter that can turn and record the energy flow in both directions. This meter then measures the household's electricity consumption and the quantity transmitted to the main electricity grid. Net metering allows the residential home to produce electricity from the rooftop solar PV system connected to the main electricity grid to meet the household load profile.

Net metering policies vary from region to region and from country to country. These policies may denote how much the compensations are worth and how long the customer can retain them. The policies also indicate which renewable energy technologies are eligible for net metering and whether respective installed or aggregate capacity limits exist.

On the basis of how net metering functions, it uses a metre that spins and records excess energy flow from the residential solar PV system to the primary electricity grid during the day, as shown in Figure 4. On the other hand, during the night, the residents record energy received from the primary grid [27].

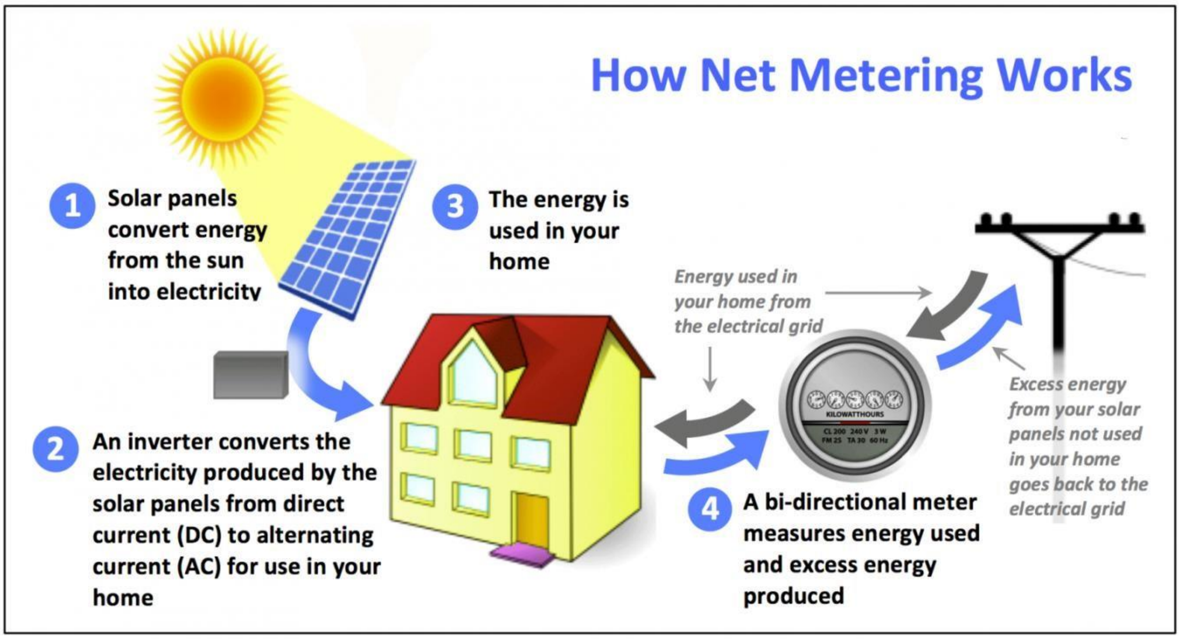


Figure 4: Net Metering [27]

It is worth noting that net metering works for grid-connected systems, allowing the customers to be billed only for the net electricity consumed [28]. If less electricity is used, the residents' consumption net product is expected to have a positive gain of renewable energy credits (REC) in some countries.

2.2 Benefits of Net Metering

Generally, net metering is the mechanism that promotes the distribution of energy, which is generated by the prosumers, thus increasing energy access [14]. Net metering has several benefits for the utility company, community and customers. Firstly, well-designed net metering policies can play a crucial role in providing a friendly environment that is of low-cost, simple and easily administrated for residential PV systems [13]. Secondly, the small PV systems installation can assist in boosting the utility capacity and the electricity supply. Thirdly, Poullikkas et al. indicated that net metering improves access to electricity at a low cost to improve the electricity supply to meet the demand.

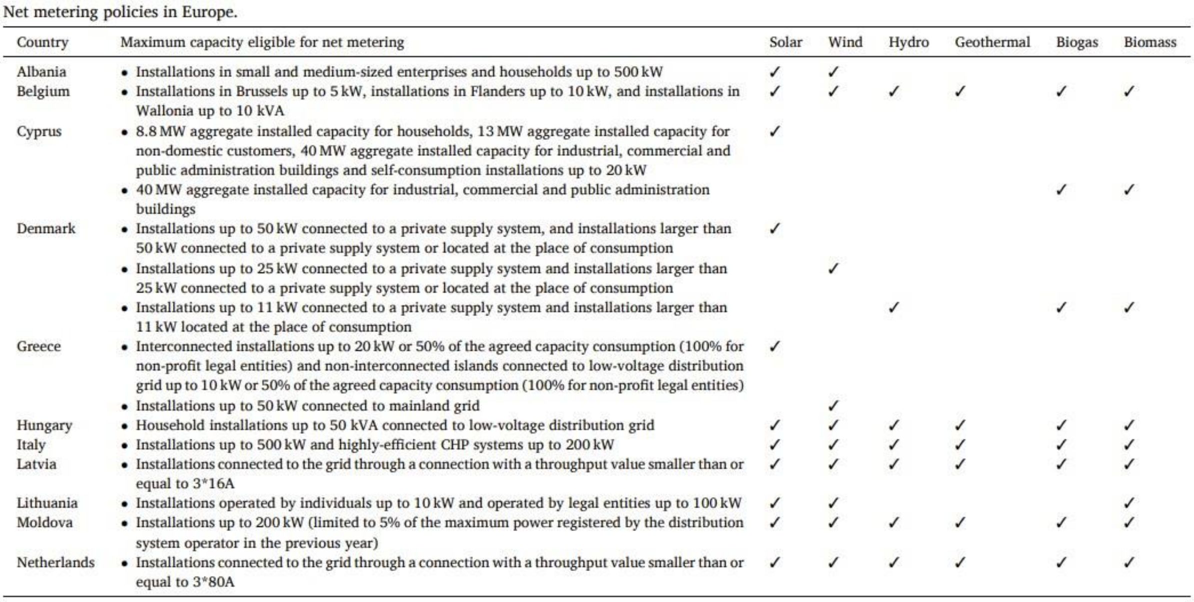
The grid-connected solar PV systems benefit from the correlation between the peak daily need and the maximum daily radiation for solar power generation [29]. The sunshine predictability calculations are more manageable. Therefore, grid-connected solar PV systems are considered as the high load-carrying capacity for the territory under the service. The utility company gains more energy generation sources under the service territory paid by the customer. This extra electricity production assists the distribution to the local community and increases energy access. The electricity access increase implies more people will be added to the grid connection without overloading the electricity supply. The distribution also strengthens the electricity capacity as the voltages weaken on the long distribution lines under high load and breakers drop. However, under net metering, the power generation is produced under short distribution lines to maintain the voltage of the electricity to the local customers. Thus, it is important to consider net metering to take advantage of solar PV power generation to strengthen the voltage and improve service delivery to the local rural communities. As indicated, the customers also gain through the low-cost, long-time power consumption and security of supply while the community benefits through the local power generation investment and promotion of business opportunities. The extensive rise of distributed generation globally results from energy net metering. The prosumers also benefit from the excess electricity supply from their power production, compensated and/or credited depending on the rules and regulations established to guide net metering.

2.3 Review of Other Countries' Net Metering Policies

Many countries implement net metering policies globally [15], [31]. These countries include the United States of America, the European Union (Belgium, Cyprus, Denmark, Italy, Netherlands, to mention but a few), Asia (Thailand, India), and Africa (South Africa (partially implemented), Benin, Burkina Faso, Kenya, Cape Vrede, Zimbabwe (improperly implemented) and Namibia, amongst others) [13], [15], [30]. Different countries apply various net metering policy directions, which need to be studied clearly to provide the policy guidelines for Lesotho as seen in sections 2.3.1 and 2.3.2.

2.3.1 Belgium

Countries, such as Belgium, set the net metering at different minimum capacities required to qualify to participate in the net metering systems, as shown in *Figure 5*. For example, Belgium set the minimum power at 5kW for the Brussels region, and the prosumer is compensated by the excess electricity transmitted to the grid, but not utilised [31]. However, the Flanders region uses the 10kW minimum eligibility criterion, which has no compensation for the excess delivered to the primary grid. In comparison, the Wallon region uses 10 kVA as the customer minimum eligibility criterion to participate in net metering.



Net metering policies in Europe.

Country	Maximum capacity eligible for net metering	Solar	Wind	Hydro	Geothermal	Biogas	Biomass
Albania	• Installations in small and medium-sized enterprises and households up to 500 kW	✓	✓				
Belgium	• Installations in Brussels up to 5 kW, installations in Flanders up to 10 kW, and installations in Wallonia up to 10 kVA	✓	✓	✓	✓	✓	✓
Cyprus	• 8.8 MW aggregate installed capacity for households, 13 MW aggregate installed capacity for non-domestic customers, 40 MW aggregate installed capacity for industrial, commercial and public administration buildings and self-consumption installations up to 20 kW	✓					
	• 40 MW aggregate installed capacity for industrial, commercial and public administration buildings					✓	✓
Denmark	• Installations up to 50 kW connected to a private supply system, and installations larger than 50 kW connected to a private supply system or located at the place of consumption	✓					
	• Installations up to 25 kW connected to a private supply system and installations larger than 25 kW connected to a private supply system or located at the place of consumption		✓				
	• Installations up to 11 kW connected to a private supply system and installations larger than 11 kW located at the place of consumption			✓		✓	✓
Greece	• Interconnected installations up to 20 kW or 50% of the agreed capacity consumption (100% for non-profit legal entities) and non-interconnected islands connected to low-voltage distribution grid up to 10 kW or 50% of the agreed capacity consumption (100% for non-profit legal entities)	✓					
	• Installations up to 50 kW connected to mainland grid		✓				
Hungary	• Household installations up to 50 kVA connected to low-voltage distribution grid	✓	✓	✓	✓	✓	✓
Italy	• Installations up to 500 kW and highly-efficient CHP systems up to 200 kW	✓	✓	✓	✓	✓	✓
Latvia	• Installations connected to the grid through a connection with a throughput value smaller than or equal to 3*16A	✓	✓	✓	✓	✓	✓
Lithuania	• Installations operated by individuals up to 10 kW and operated by legal entities up to 100 kW	✓	✓				✓
Moldova	• Installations up to 200 kW (limited to 5% of the maximum power registered by the distribution system operator in the previous year)	✓	✓	✓	✓	✓	✓
Netherlands	• Installations connected to the grid through a connection with a throughput value smaller than or equal to 3*80A	✓	✓	✓	✓	✓	✓

Figure 5: Net Metering Policy in Europe [30]

2.3.2 Africa

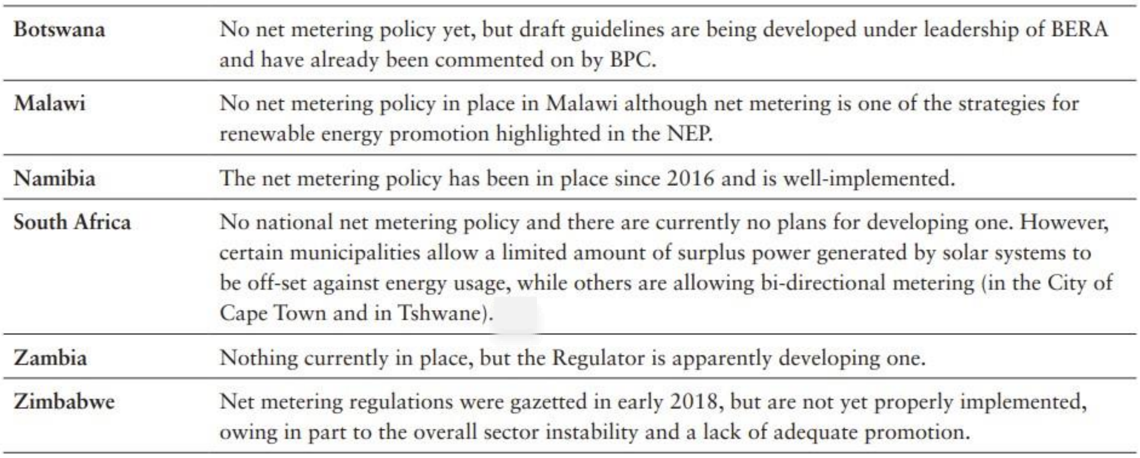
The African continent has also engaged and promoted the use of the net metering mechanism to increase energy access and encourage business development. In several countries, such as Ghana, Namibia, South Africa and Zimbabwe, the net metering policies have been fully or partially or improperly implemented respectively. Moreover, developing a conducive environment to attract more investors and independent power producers in the renewable energy sector to upgrade the business sector and improve the quality of life can be achieved by Independent Power Producers (IPPs) in Africa [32]. Net metering promotes the business development and distribution of these renewable energies. South Africa Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) is the renewable energy policy that has attracted many investors and promoted clean technologies in South Africa.

As reflected in *Figure 6*, the South African partial net metering in Cape Town and Tshwane cities seems to have gained momentum through this REIPPPP. South Africa has used a net metering mechanism to increase power generation and improve the energy mix. Most residents and the commercial sector expected the payback of the project under development within three years [15].

The net metering of Zimbabwe (improperly implemented) allows the household producers to measure and get payment on the excess net credit of electricity produced [33], as illustrated in Figure 6. This mechanism assists households in reducing their bills and helps the Zimbabwe Electricity Supply Authority (ZETDC) to lessen its dependence on imported electricity, thus reducing its foreign expenditure. Lesotho therefore may consider options for implementation of solar PV net metering to reduce the foreign bills due to imported electricity like Zimbabwe does. Furthermore, Olowosejeje *et al*. showed that increasing access to clean energy alternatives lowers emissions and energy costs for Africa [34]. They concluded that the energy policies must address economic, social and environmental implications. The South African region's feasibility study favours sustainable energy that entails climate change mitigation [32], [35]. The authors further highlighted that the projects must implement carbon incentive programmes to improve access to finance, implement policy mechanisms, disseminate information and technology and initiate sectoral reforms and community engagement.

The Zimbabwean net metering (improperly implemented) operates in parallel and safely with a single-point intersection with the distribution network. The customer or producer is compensated with a credit of 0.9kWh at the end of the billing period [36]. However, this is just compensation for the monthly electricity bill charges, not in monetary value.

The net metering system for Namibia is meant to add power to the national grid while providing a conducive environment to attract investors into energy generation investment. It also promotes renewable energy and alleviates the quantity of electricity imported to the country. The net metering system also improves investment in small solar energy projects and promotes customer production to export the distribution network while reducing unemployment. The solar energy power production should not exit the circuit brake at the 500 kVA determined by the distribution company and approved by the board of directors. The back feeding net metering must have a visibly open, lockable and manual disconnect switch that is accessible and labelled easily [26]. This promotes safety standards and easy access to the net metering system under a fully flashed labelling guide of operation.



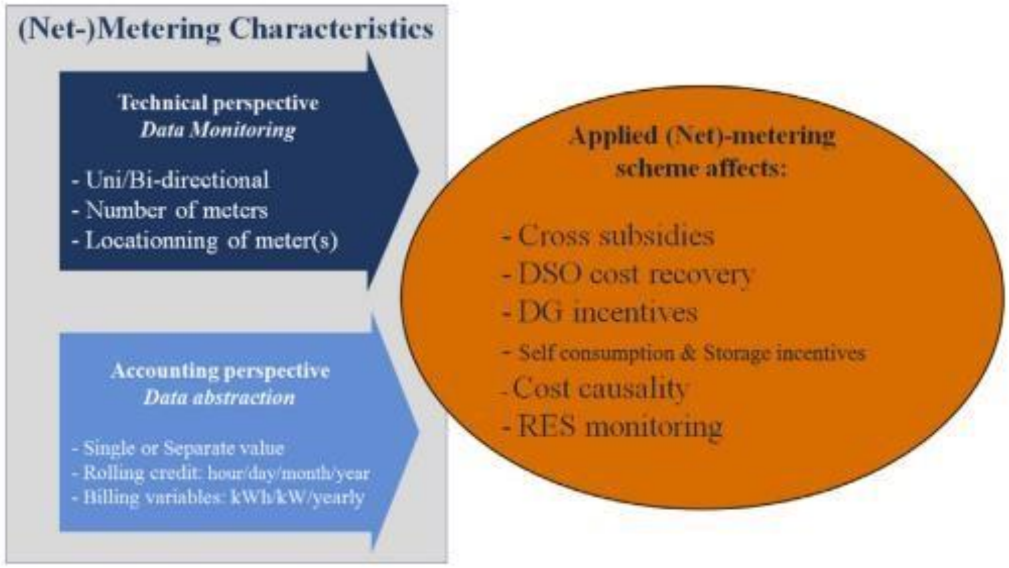
Botswana	No net metering policy yet, but draft guidelines are being developed under leadership of BERA and have already been commented on by BPC.
Malawi	No net metering policy in place in Malawi although net metering is one of the strategies for renewable energy promotion highlighted in the NEP.
Namibia	The net metering policy has been in place since 2016 and is well-implemented.
South Africa	No national net metering policy and there are currently no plans for developing one. However, certain municipalities allow a limited amount of surplus power generated by solar systems to be off-set against energy usage, while others are allowing bi-directional metering (in the City of Cape Town and in Tshwane).
Zambia	Nothing currently in place, but the Regulator is apparently developing one.
Zimbabwe	Net metering regulations were gazetted in early 2018, but are not yet properly implemented, owing in part to the overall sector instability and a lack of adequate promotion.

Figure 6: SADC Net Metering status [34]

2.4 Net Metering Policy Classification

Net metering has technical and financial classifications that provide the policymakers with the direction of enforcement and implementation [37], as demonstrated in Figure 7. Net metering uses uni-directional and bi-directional metres. The uni-directional metre measures electricity consumption only in one direction, while the bi-directional metre can measure both production and consumption. However, the bi-directional metre mainly measures net electricity consumption under net metering.

Net metering may be used as the electricity feed-in and consumption measure of the financial aspects of the credit gain [37]. Ultimately, it is calculated from a single net value for both consumption and production. Net metering creates the storage of the electricity to the primary electricity grid that is used when the surplus of electricity production is achieved simultaneously. This electricity will be used during another period to cover times when electricity production is minimal. As shown in Figure 7, this crediting period is called the rolling credit timeframe (hourly, daily, monthly or yearly).



F*igure 7: Net Metering and its influence on energy policy criteria [36]*

2.5 Policy Design Decisions

The design of the net metering policy depends on three frameworks for compensation of regulators types to follow during the implementation. These design decision frameworks are accounting, restrictions and granularities.

2.5.1 Accounting

The accounting framework refers to the decisions that accrue between the power energy generator and the distribution company [38]. This framework can be credited through either energy credits or monetary credits. The energy credit compensation is done to award the energy generator on the surplus of energy generated above the household energy consumption. It should be noted that the net metering scheme needs to define whether crediting is for the prosumer, regulator or utility company. The other way to credit the prosumer is through the monetary terms on the surplus of solar power generation against household consumption [38]. The prosumer is paid money for the excess of production from consumption as the means of compensation.

2.5.2 Restrictions Net Metering

The restrictions net metering is formulated under the limitations and standards that guide the entrepreneur or the household to comply with the stability of the utility grid and operations structure [38]. The monetary credits require a clear agreement on the transaction fee, service fee or premium rate. Furthermore, monetary credits should also prove the precise application of net metering systems' technical and financial standards. The standards would guide whether restrictions or unlimited installation quantity and capacity are possible. However, net metering without limitations and standards would result in grid instability even if it could attract more household investment and participation [28], [37], [38], [39]. Moreover, the net metering system standards should consider residential transmission codes and guidelines.

2.5.3 Granularity Net Metering

The granularity of the net metering system can be spatial or temporal depending on the type of grouping for the net metering system [38]. Temporal net metering is where the solar PV minigrid is developed, and net metering is based on timeline partitions. It is, however, not friendly for development because it requires much technical expertise and experience. In contrast, spatial net metering is based on regional groupings, like community grouping [38].

2.6 HOMER Pro Modelling

The HOMER Pro software is a Hybrid Optimisation Model for Electric Renewables software developed by the National Renewable Energy Laboratory of the United States [40]. The HOMER assists in the planning of different control plant setups. It has diverse built-in components, such as PV arrays, wind turbines, utility loads of various kinds, generators, converters and battery backup. It recreates different schematics of control of plants and configures the optimum model to achieve the optimised operational costs, NPC, gas emissions and comparison of the economic factors.

The HOMER Pro performs three primary tasks based on raw data provided by the user. These three tasks are simulation, optimisation and sensitivity Analysis. It can also simulate a variety of power combinations, such as PV arrays, wind turbines, utility loads, generators and battery backup. The simulation gives basic information about two key factors. First, it determines the feasibility of the power system. Second, it provides a complete estimate of the life cycle cost of the power system under examination. This cost includes the power system's installation and operating and/or running costs [41]. However, the current study only concentrated on the MASOWE Residential sector's solar PV component and net metering analysis.

2.7 Load Profile Development

On the one hand, the Lesotho Electricity Company defines the double hump typical load profile as displayed in Figure 8. Where the typical Lesotho energy load profile indicates that the maximum household consumption is at 6 am with a load factor of 0.08 and at 7 pm with a 0.07 load factor. As illustrated in Figure 8, there is also little electricity consumption during the lunch hour. On the other hand, the South African household load profile shown in Figure 9 reflects more energy consumption at 8 am and mainly at 8 pm [42]. Both Lesotho and South Africa load profiles show maximum energy consumption between 6 am and 8 am for the morning hours and 7 pm and 8 pm for the evening hours, respectively, forming the double hump load profile. For that reason, this study's load profile has to follow a similar pattern.

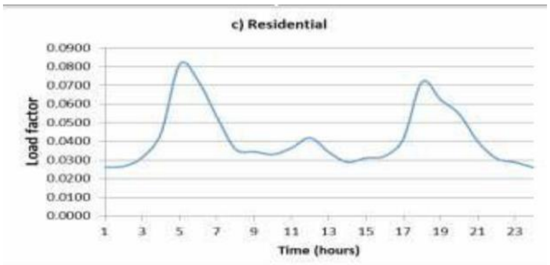


Figure 8: Typical residential load profile from LEC

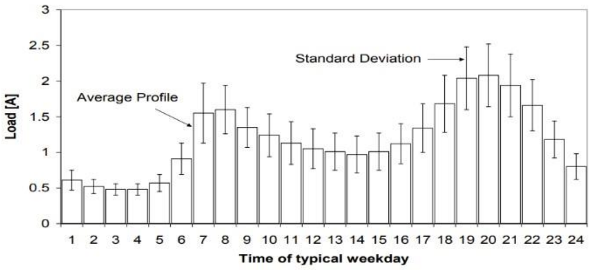


Figure 9:Typical residential household in South Africa [42]

Similarly, the scoping exercise to determine load profile solar co-generation models in Figure 10 and Figure 11 was developed for a typical remote African country and Botswana load profile comparisons, correspondingly [43]. Prinsloo *et al*. concluded that typical Africa load profiles follow a similar double hump with slightly different morning and after peak demand [43].

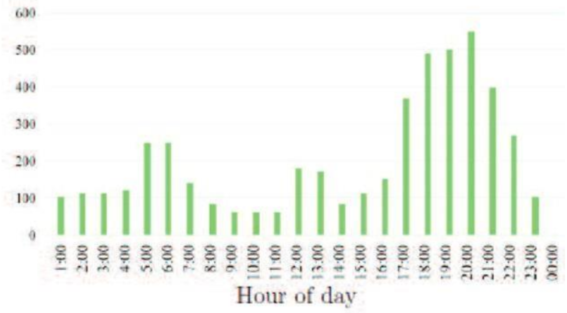


Figure 10: Daily African rural energy load profile [43]

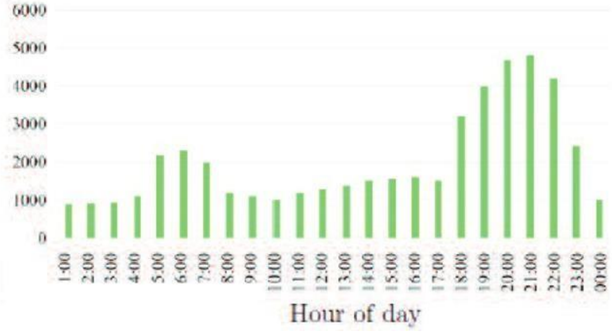


Figure 11: Botswana load profile [43]

The matrices by Dlamini and Cromieres for implementing peak load reduction algorithms for household electrical appliances were used to develop the MASOWE load profile [44]. The used

$Lt=i=1naitPi$ (1)

considers the *n* collections of appliances for the house at time *t*, which is defined as follows:

$L_t = \sum_{i=1}^{n} a_{it} P_i$ (1)

where,

L_t is the household hourly peak demand of electricity (Wh); a_{it}
is the percentage consumption of electricity per hour (%); P_i is
the household appliance power (w).

The matrix multiplication of the percentage consumption of electricity is then performed.

a_{it} means against the individual household's total power usage of each type of appliance P_i to find hourly peak electricity demand L_t in a day. Then, the hourly peak demand matrix in equations $a10P1+a20P2+a30P3+\ldots+a_{n0}P_n=L_0$ (2)
can be expressed as follows:

$$a_{10}P_1 + a_{20}P_2 + a_{30}P_3 + \cdots + a_{n0}P_n = L_0 \qquad (2)$$
$$a_{11}P_1 + a_{21}P_2 + a_{31}P_3 + \cdots + a_{n1}P_n = L_1\ a$$
$${}_{12}P_1 + a_{22}P_2 + a_{32}P_3 + \cdots + a_{n2}P_n = L_2$$
$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots \qquad \vdots$$
$$a_{1r}P_1 + a_{2r}P_2 + a_{3r}P_3 + \cdots + a_{nr}P_n = L_r$$

$a10\ \ a20\ \ a30 \ldots an0a11\ \ a21\ \ a31 \ldots an1\ a12\ \ a22\ \ a32 \ldots\ an2: \quad : \quad : \ \ldots \ :a1r$
$a2r\ \ a3r \ldots\ anrP1P2P3{:}Pn{=}L0L1L2{:}Lr$ (3):

$$a_{10}\ \ 20\ \ 30\ \ a\ \ a\ \ \ldots a_{n0}\ P_1\ \ L_0$$
$$a_{11}\ \ 21\ \ 31\ \ a\ \ a\ \ \ldots a_{n1}\ P_2\ \ L_1$$
$$a_{12}\ \ 22\ \ 32\ \ a\ \ a\ \ \ldots\ a_{n2}\ P_3 \ | = |\ L_2$$
(3)
$$:: \quad : \ \ldots \ : \quad : \quad :$$
$$\Big\backslash\ {}_{1r}\ \ {}_{2r}\ \ {}_{3}a\ \ a\ \ a_{r} \ldots\ a_{nr}) \Big\backslash P_n \Big/ \quad \Big\backslash L_r \Big/$$

The entries L_0 to L_r in equations $a_{10}P_1 + a_{20}P_2 + a_{30}P_3 + \cdots + a_{n0}P_n = L_0$
(2) and (4) for this study are represented by L_0 to L_{12} to form the matrix of 12 by 1 from the multiplication of 12 by 12 and 12 by 1 matrices. This method gives the MASOWE household load profile as input into the HOMER Pro model to size on grid hybrid solar PV system for net metering modelling.

2.7 Review of Solar PV Costs

Climate change has affected the whole world negatively or positively [45], [46], [47]. The situation forced the international community to adapt and mitigate climate change's effects on living creatures. Therefore, the world transformed energy from conventional energy to primarily solar and wind hybrid, working simultaneously to meet the energy demand. The solar irradiance and types of solar PV and their installations play a crucial role in ensuring the accuracy of the results.

2.7.1 Economic Review of Net Metering

The Levelised Cost of Energy (LCOE) analysis determines the solar PV system energy price and compares different production methods [48]. As shown in Figure 12, the LCOE for solar PV systems has declined by 88% from \$0.417/kWh to \$0.043/kWh between 2010 and 2021 [49]. The PV system's low cost has attracted many countries to promote renewable energy. These costs also make it viable for the net metering mechanisms to promote energy access and generation. Other than the LCOE, the factors that make the countries decide on the net metering system are the internal rate of return (IRR), return on investment (ROI) and payback period. The systems of different sizes with the same IRR may encourage the prosumers to participate in the larger system installations under an incentivised self-consumption system, but it discourages the disincentivised prosumer [25]. However, the small-sized system is the best option for the household under the disincentivised system [50]. The incentivised net metering systems are the customer self-consumption and customer-funded. Pacudan further indicates that net metering provides more incentives for those customers who contribute [50].

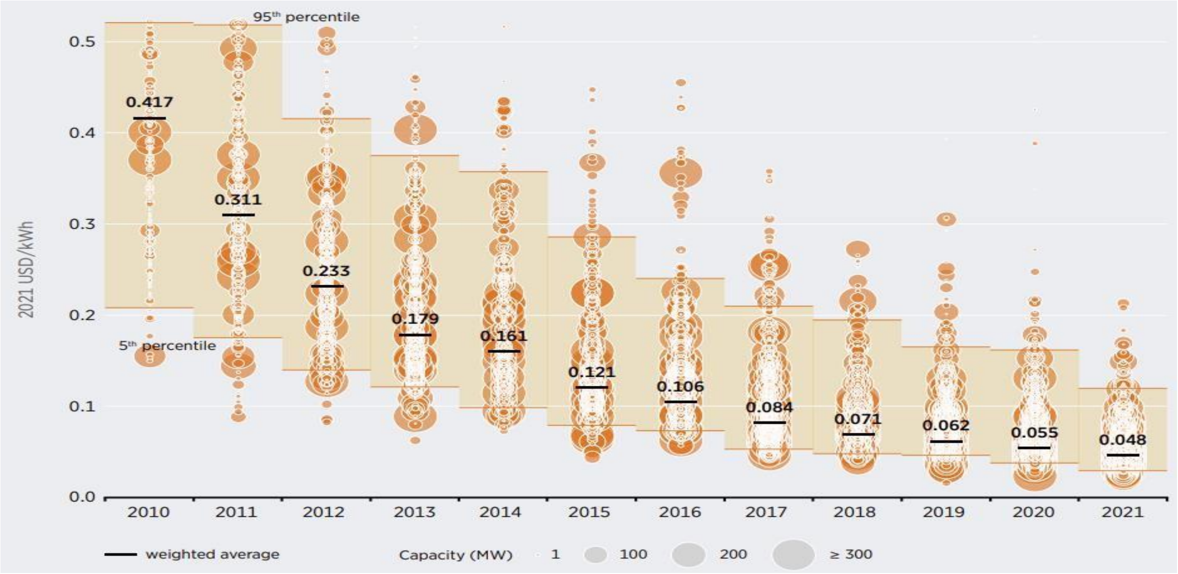


Figure 12: Global utility-scale solar PV project LCOE [49]

2.8 Economic Equations

The economic equation provides the parameters and economic indicators that the study uses to conclude on the viability and feasibility of net metering systems. The economic indicators used are the Net Present Cost, Cost of Energy, Internal Rate of Return, Levelised Cost of Energy and Return on Investment.

2.8.1 Net Present Cost (NPC)

The net present cost (NPC), as presented by equation (4), provides the difference between the present value of cash inflow and the electricity-generated revenues against the cash outflow over a while. The investor has to find out whether the investment into net metering positively influences the investment. Therefore, the NPC has to be the lowest to attract investment and implement the project effectively [51].

$$NPC = \frac{C^{ann}}{CRF(i.R)} \qquad (4)$$

C_{ann} – the total cost of installation, maintenance, replacement, fuel, electricity purchased, capacity storage and emission penalties.

$CRF(i.R)$- the recovery factor of investment depending on the real interest rate (i) and duration of the project. The recovery factor is expressed in the equation (5) below:

$$CRF(i,R) = \frac{i(1+i)_R}{(1+i)^R-1} \qquad (5)$$

The real interest is based on the nominal (i) and the inflation rate (f) performance, as shown in

$i0-f1+f$ (6)

below:

$$i = \frac{i^0\_f}{1+f}$$

(6)

2.8.2 Cost of Energy (COE)

The most crucial parameter that provides the economic value of the system in average cost per kilowatt-hour of electricity produced is the cost of Energy (COE) [52]. The HOMER software provides the COE using equation *(7)* below: $C_{\underline{ann.t}}$

$$COE = \frac{}{E_{served}} \qquad (7)$$

$C_{ann.t}$ – total annual project cost

E_{served} – the amount of energy produced (kWh/year)

$Cann.t-Cann.cl$ (8) below:

$$OC = C_{ann.t} - C_{ann.cl} \qquad (8)$$

The COE is vital for comparative competitiveness between solar PV power production and electricity from the grid [52].

2.8.3 Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) provides for the potential profitability of the investment of the net metering for the electricity use and generation for the MASOWE residential sector. The IRR shown in equation (9) is the discount rate that makes the NPV equation equal to zero as part of the cash flow analysis.

$$IRR = \sum_{t=1}^{n} \frac{R_t - C_t}{(1+i)^t} = I_0 \qquad (9)$$

2.8.4 Levelized Cost of Energy

$+\Sigma\ {=}1\overline{(1+r)^t}$ I nt ct

The LCOE equation $LCOE=$ $\Sigma\ {=}1\frac{E_t}{(1+r)}$ n

(10)

t t

provides the average net present cost of electricity generated over the project's lifetime. The significance of the LCOE for Net Metering is important to verify whether it would be a good decision for the investor to invest in this system. The LCOE has to be low to make the project attractive and beneficial to the MASOWE residential householder. The Economic model for this study uses LCOE as follows:

$$= \frac{I+\sum_{t=1}^{n}\overline{(1+r)^t}}{\sum_{t=1}^{n}\frac{E_t}{(1+r)}} \quad {}^{ct} LCOE_{t} \qquad (10)$$

Where,

C_t is operational and management expenditure for the year t; E_t is the energy yield in year t; I is the initial investment, and n is the investment period.

2.8.5

$GT1=GDcos\theta cos\theta zGBG0+1-GBG01+cos\beta21+GBGB+GDsin3\beta2+G\beta+GD\rho g1-cos\beta2$

(11)

(11) to provide the energy efficiency of the PV panel on the tilted surface [53]. The tilt angle for Lesotho is 30° calculated as the Lesotho correction factor.

$$_1 = G_D \left[\left(\frac{\cos\theta}{\cos\theta_z}\right)\left(\frac{G_B}{G_0}\right) + \left(1 - \frac{G_B}{G_0}\right)\left(\frac{1+\cos\beta}{2}\right)\left[1 + \sqrt{\frac{G_B}{G_B + G_D \sin^3\left(\frac{\beta}{2}\right)}}\right]\right] + (G_\beta + G_D) \quad 2 \quad ^{1-\cos\beta} \quad G_T \quad \rho g \, \underline{\qquad}$$

(11)

The energy simulations are convenient for modelling the instantaneous PV power generation output. $\boldsymbol{P_{PV}}$ the equation in $\boldsymbol{PPV} = \frac{PV}{\quad} \cdot \frac{T}{\quad} \cdot \eta^{\eta_{STC}} G^{G_{STC}} \qquad \boldsymbol{P_{STC}}$

(12) below provides that the solar PV power generation is given by:

$$\boldsymbol{P_{PV}} = \frac{\overset{\eta}{PV}}{\quad} \cdot \frac{\overset{G}{T}}{\quad} \cdot \eta_{STC} \qquad G_{STC} \qquad \boldsymbol{P_{STC}}$$

(12)

Where the parameters are defined as follows:

$\boldsymbol{\eta_{PV}}$ is the instantaneous cell-temperature-dependent PV efficiency;

$\boldsymbol{\eta_{STC}}$ is the PV efficiency at standard test conditions (STC)

$\boldsymbol{G_T}$ is the solar irradiance incident on the plane of the PV array/module;

$\boldsymbol{G_{STC}}$ is the in-plane incident solar irradiance at standard test conditions (= 1000W/m^2 at 25°C cell temperature);

$\boldsymbol{P_{STC}}$ is the rated power output of the PV cell, module or array measured at STC;

2.8.6 Net Metering Analysis

The average 24-hour load consumption and PV production profile for net metering for the Mediterranean load profile are shown in *Figure 13* [54]. This Mediterranean load profile shows net metering to calculate pre- and post-installation of PV system scenarios and provides the financial indicators. The current study follows the same comparison of consumption and PV production done by Koumparou et al. [54] to perform the MASOWE solar PV net metering system.

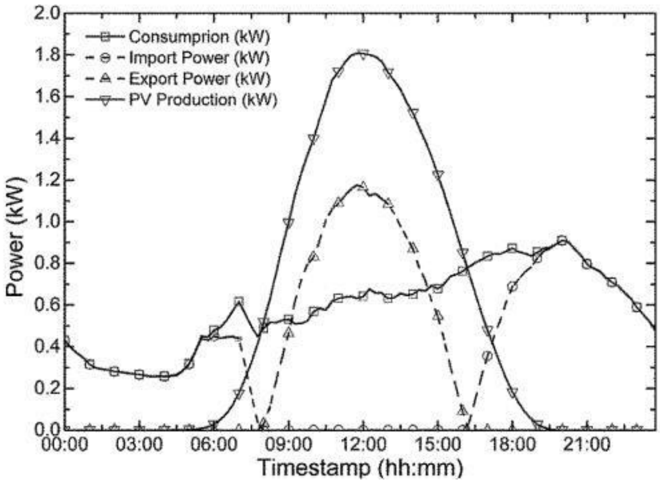


Figure 13: Average 24-hour load consumption vs. PV production profile for the Mediterranean Region [54]

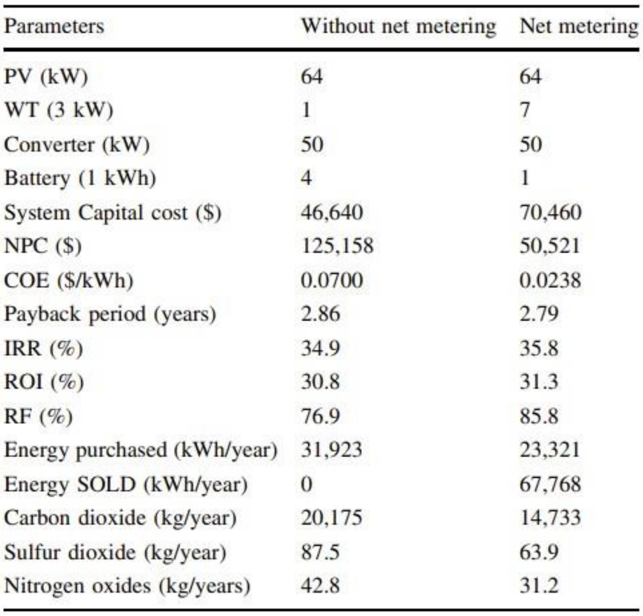
Several studies on net metering have shown the importance of discount rate, inflation rate, average solar radiation and initial components to find the impact of cost efficiency [55]. Therefore, the power generation cost and electricity to households remain crucial for studying net metering. However, when comparing stand-alone and grid-connected roof-mounted solar PV systems for Abu Dhabi net metering, Alhamad concluded that PV power generation lowers the power generation costs of various companies, thereby lowering electricity prices [55]. Alhamad further showed that the renewable energy resources study could also assist in lowering the costs associated with system equipment and operational costs.

Moreover, Alhamad added that increasing renewable energy reduces the use of fossil fuels as fossil fuel prices increase against lowering prices of renewable energy [55]. The situation, as mentioned by Alhamad, can influence governments and policymakers to remove constraints and promote renewable energy. It was concluded that this situation needs the addition of intensive subsidies. Moreover, renewable energy net metering remains the best option for a clean and environmentally friendly energy source without a carbon footprint [52]. It was recommended that it could be better to consider the environmental issues while addressing the issues of energy demand and accessibility under the net metering system.

The study of net metering by Jia *et al*. showed that the investment costs are related to solar radiation and electricity demand, which affect performance efficiency [52]. Consequently, all prices, including installation costs, will remain lower [48]. However, Wijeratne *et al*. showed that the PV net metering system residential project should consider the geophysical, technical, economic and environmental aspects [56].

2.9 Comparison of Power Production vs. Consumption

There is another study on the design and modelling of a grid-connected PV-WT hybrid microgrid system using a Net Metering facility. This study compares grid systems without net metering with grid-connected net metering systems technical and economic analysis for Pakistan [57], as shown in Figure 14. In the study, net metering was promoted, and it was recommended that these models should be compared for perfect results to influence the political decision-makers for future decisions in policy-making. Furthermore, Shaikh et al. concluded low prices and the economic viability of net metering would influence political decision-makers' future decisions in policy-making [57]. This study was made for Pakistan in South Asia in the northern hemisphere The comparison of grid systems without net metering against grid-connected net metering systems' economic implications was not performed for the MASOWE community in Lesotho. This provides the gap that this study has to be addressed by comparing the economic effect of net metering without a grid connection against a net metering system connected to the grid. Therefore, the study extends the PV net metering study that was performed in Lesotho by comparing the economic effect of the grid without net metering against the grid-connected net metering system using MASOWE as the sample.



Parameters	Without net metering	Net metering
PV (kW)	64	64
WT (3 kW)	1	7
Converter (kW)	50	50
Battery (1 kWh)	4	1
System Capital cost ($)	46,640	70,460
NPC ($)	125,158	50,521
COE ($/kWh)	0.0700	0.0238
Payback period (years)	2.86	2.79
IRR (%)	34.9	35.8
ROI (%)	30.8	31.3
RF (%)	76.9	85.8
Energy purchased (kWh/year)	31,923	23,321
Energy SOLD (kWh/year)	0	67,768
Carbon dioxide (kg/year)	20,175	14,733
Sulfur dioxide (kg/year)	87.5	63.9
Nitrogen oxides (kg/years)	42.8	31.2

Figure 14: Grid without net metering vs. net metering power generation [57].

2.10 Net Metering Policies Review

There are unlimited studies worldwide on Solar PV net metering however there has not been enough investigation on the effects of solar PV net metering for Lesotho. The situation makes it necessary for more studies on net metering to find an effective and efficient net metering system for Lesotho. The previous Lesotho feasibility of net metering study evaluated the techno-economic implications for Lesotho PV electricity net metering [30]. Moleko found that under the current tariff solar PV net metering system for the residential sector is technical and economically viable [30]. However, this study recommended further investigation on the cost analysis of solar PV net metering systems. Moleko's study did not consider the fact that most of the highland areas are not connected to the grid but already use solar PV for off-grid power supply [30]. Moreover, that previous net metering study ignited the need to investigate more net metering systems to provide efficient and effective options for developing the Lesotho net metering system. Therefore, this study extends the previous net metering to research more using fully electrified MASOWE as the sample for the immediate option to pilot this net metering system. Moreover, MASOWE is fully connected to the grid providing for chances of near future net metering. This situation of being grid connected provides more advantages for net metering other than areas not connected to the grid, which are considered economically not viable by the utility to connect to the grid in the new future. Therefore, this marks the remaining gap for Lesotho's net metering economic impact for MASOWE and it is critical to conclude on the cost implication. The different net metering systems are developed and learnt to find the best optimum LCOE as the system is doubled.

The literature reflects whether the net metering system has worked effectively in the previous study of net metering and PV self-consumption in emerging countries [15]. In comparison, Namibia is a Southern African Community Development Community (SADC) member implementing net metering. This Namibia net metering is investigated and researched for its suitability for the Maseru South West (MASOWE) community in Lesotho. Furthermore, net metering can be used to improve the power supply to meet the energy demand while at the same time promoting renewable energy use and protecting the environment. The study has to examine the remaining gap highlighted by Moleko on the economic cost implications to find the feasibility of net metering for MASOWE as the sample study area [30]. This gap is tackled through a comparison of the economic cost implication of net metering without a grid connection against a net metering system connected to the grid. Shaikh et al. showed that low prices and the economic viability of net metering would guide policy decisions [57]. Therefore, this study investigates net metering guiding policy options as unaddressed in the previous studies. The methodology of this study provides the path that can be used as an option for the analysis of the net metering economic feasibility.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

The solar PV net metering method is determined by first developing the energy consumption load profile. The HOMER Pro system uses the load profile to size and optimise solar PV system technical and economical requirements for Net Metering. The study also uses the Prinsloo scoping exercise method to determine load profile archetype reference shapes for solar cogeneration models in off-grid rural African Villages [42]. Furthermore, the study adapts Koumparou et al.'s method to determine the technical and economic feasibility of net metering [54]. The method provides different scenarios of net metering on and off-grid, evaluating the economic feasibility and avoiding the cost of energy under net metering. Then, the methodology provides the option to analyse the possible policy for net metering.

3.1 Overview

The study designed the rooftop solar PV net metering system that supplies electricity to the utility main grid for the Maseru South West (MASOWE) residential sector. The research frame of analysis provided in *Figure 15* illustrates the methodological approach that was undertaken in this study [58]. The software that was used for this study includes the HOMER Pro and Excel to analyse and predict the possible uses of net metering. Firstly, the pre-HOMER Pro process is performed using Excel to develop a load profile. Secondly, the HOMER Pro provides the techno-economic analysis while simultaneously comparing the equipment's wide range under different constraints and performing sensitivity analysis [58]. Finally, the system's technical properties and life cycle cost (LCC) are compared and displayed in the optimised hybrid system. The study of the LCC uses the initial capital cost, maintenance, and operations cost to find the LCOE over the system's lifespan. Then, the HOMER Pro satisfies the demand using the alternative technology options and resources available to find the optimum model.

The post-HOMER Pro process computes the system's environmental, cost and economic analysis to derive the feasible net metering policy direction.

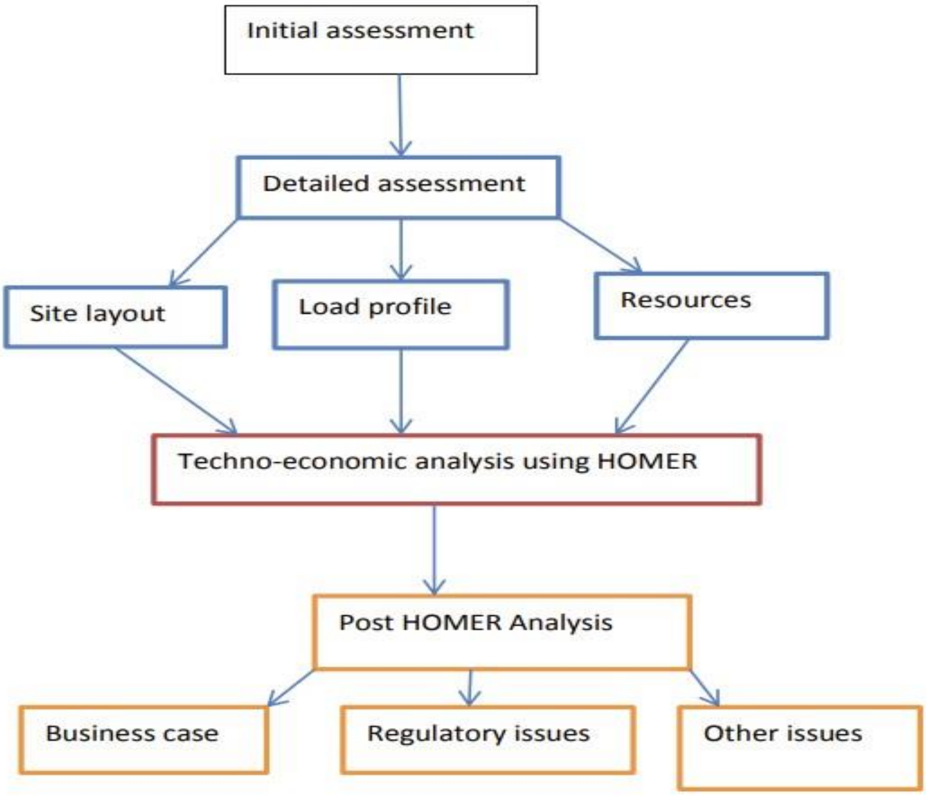


Figure 15: Framework of analysis [58]

The study performed the following functions:

a) It designed the optimum solar PV net metering scheme for the MASOWE residential sector.

b) The system sized the solar PV required to balance the demand and supply of electrical energy for the MASOWE residential sector.

c) It assessed the technical and economic viability of net metering for the MASOWE residences.

d) It performed the cost and benefit analysis of net metering.

e) The utility cost was analysed to find the viability of the energy cost of the grid without net metering and compare the costs of energy with net metering for solar PV connected to the grid.

f) It suggested possible net metering policy guidelines to enforce the Lesotho Energy Policy.
    - Different policies were assessed to provide the possibility of developing and enforcing the net metering policy for Lesotho.
    - The international policies were assessed for possible domestication to provide viable provisions for net metering development.

The technical feasibility analysis assesses the electricity demand and supply for the households from the solar PV system connected to the main LEC electricity grid. Therefore, for this assessment, the study uses the HOMER Pro to simulate the combination of the different sizes configurations based on the load and solar radiation amount to balance each system component [52]. The ultimate objective is to perform an economic analysis of the feasibility of MASOWE residents' net metering system.

3.2 Techno-Economic Data

The study used the preliminary data from the Bureau of Statistics to derive the load profile for the MASOWE residential sector. The study also used secondary qualitative and quantitative data from the Lesotho Electricity Company (LEC) and the Department of Energy (DOE). The electricity appliance wattage for the MASOWE residents was acquired using the Demand Matrix method to derive the electricity demand that develops the consumption load profile. The study also provided the time of use of the electrical power by the MASOWE households per day. In addition, the study used the solar irradiance data from the National Aeronautics and Space Administration (NASA) prediction of the World's comprehensive energy resources (power) as the monthly averages for global horizontal radiation and monthly average air temperature over 30 years or internet data.

3.2.1 Study Area and Input Data

The net metering research for Maseru South West (MASOWE) is under the coordinates 29.364445 south and 27.487654 east. The research was performed over the individual household to find the household load profile. Later, a similar exercise was performed over 1010 households of the MASOWE community. The study further analysed weather conditions, load profile, electricity grid tariffs, equipment and features. MASOWE community is shown in *Figure 16* below.

Figure 16: MASOWE community

The resources for this study were the data from the NASA prediction of World comprehensive energy resources (power). These data were the monthly averages for global horizontal radiation from January 1983 to December 2005. Other data from the same NASA resources comprised the monthly average air temperature over 30 years from January 1984 to December 2013. In addition, the hourly electricity consumption from a typical household energy consumption for the MASOWE residential households was used to build the load profile. Moreover, the study was performed using the MASOWE community load profile for 1010 households. The load profile assumption was that all the households use similar appliances (energy saver light, refrigerator, straightening iron, geyser-electric, radio, TV, stove, phone charger, washing machine, laptop, security light, phantom loads and other base loads), with the average energy consumption.

3.2.2 Climate Data of the Region

The MASOWE Solar radiation is higher in the summer (from October to February) when the temperatures are high, and the sun's movement is in the southern hemisphere as per *Figure 17* below. Daily solar radiation is more than 5.5 kWh/m^2/day on average, making it feasible for solar energy that qualifies for the development of a solar PV net metering system. The position of the solar radiation belt makes Lesotho's location very good for solar radiation. The solar radiation belt is vital to the angle at which this radiation is received [59]. However, the clearness index is excellent in winter when there are no clouds to cause rainfall. Furthermore, the climate condition, annual cloudy days, pollutants and dust (cloud index) are other factors that influence the amount of solar energy generated.

Figure 17: Solar radiation for MASOWE

In *Figure 18* below, the temperatures in the MASOWE community are high during summer in the wet semi-arid regions, with temperatures reaching more than 15°c from October to February while the winter months, June and July, have minimum temperatures of around 5°c. However, solar energy generation is still viable for these months, making the promotion of solar PV net metering possible. Therefore, an ambient temperature is an essential and effective parameter because excessively high temperature negatively affects the solar panels' operation [59].

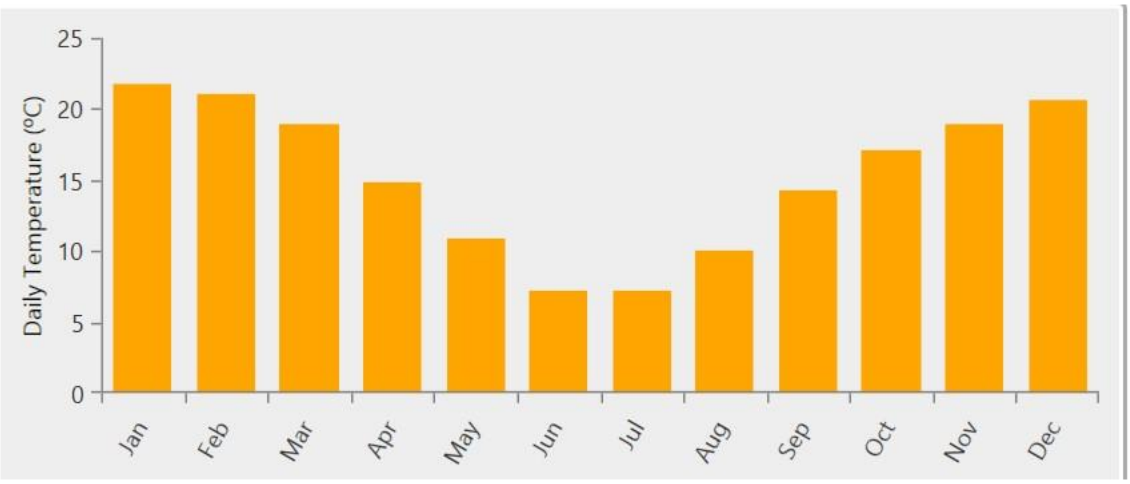


Figure 18: MASOWE temperature

3.2.3 Load Profile

The study developed the Maseru South West (MASOWE) typical electricity load profile for one household and 1010 households to reflect the average household electricity consumption pattern. The residential load profile development was mainly for the electrification design, master planning and cost of supply implementation management.

Furthermore, the MASOWE community load profile was derived by the comparison of the scoping exercise to determine the load profile archetype reference shapes for solar cogeneration models in the isolated off-grid rural African villages discovered shapes [43]. This exercise uses representative hourly reference profile shapes for a remote African village's thermal and power energy consumption. Additionally, Prinsloo et al. showed that this method of reference load shapes provided the investigational assessment between the modelled solar microsystems and automation solution [43].

The development of the MASOWE load profile used a similar shape comparison method to find the load profile used as the input of the HOMER Pro model to analyse the MASOWE load profile. The scoping exercise that modelled the African load profile by Prinsloo et al. also showed that an important feature of the household load profile is the two peaks reflected in the morning and in the afternoon, with similar patterns for different countries’ load profiles [43]. Therefore, this study’s residence load profile should be double-humped and have a similar pattern to other African Countries.

Furthermore, the study assessed the average household appliances’ energy consumption (wattage) and provided the number of appliances possible for the average MASOWE household. The study used the following criteria:

a. All energy-consuming (wattage) appliances are listed
b. Each appliance is assigned a quantity for the household
c. The quantity of appliances is then multiplied by the responding wattage to get the consumption product of each appliance
d. The demand matrix for the daily load profile is then developed as follows:
    i. Define the percentage use of each appliance over 24hrs.
    ii. All values under the demand matrix are between 0 and 1 (0% and 100%), adding to the hours each appliance uses per day.
e. The appliance’s total power is then multiplied by the corresponding demand matrix to get the daily energy demand of each appliance.

3.2.4 MASOWE Typical Load Profile

The study also adopted the Prinsloo et al. method on the scoping exercise to determine load profile archetype reference shapes for solar co-generation models in off-grid rural African Villages [43]. Similarly, the MASOWE community's load profile development uses the load profiles Figure 10 and Figure 11 developed for the typical remote African Country and Botswana load profile comparisons. Prinsloo et al. concluded that African household energy consumption follows similar double-humped peak load shapes as a reference for the development of African countries, like Botswana's load profile. The study also adopted the matrices by Dlamini and Cromieres for implementing peak load reduction algorithms for household electrical appliances [44]. This study used the matrices to define the pattern of energy consumption for MASOWE households.

3.3.5 MASOWE Load Factor Development

The study developed the load profile for the average MASOWE household in the urban area of Maseru district. The community is 100 % electrified since most residents are the working class with above-average monthly earnings. Therefore, the study assumed that all the residents have seven energy saver lights, refrigerators, a straightening iron, a geyser – electric, a radio, a television, an electric stove, four phone chargers, a washing machine, laptops, security lights and phantom loads. Furthermore, the study modelled the load profile based on Dlamini and Cromieres for implementing peak load reduction algorithms for household electrical appliance models [44].

The household energy consumption matrix was developed as per Table 1 by assigning each appliance the average wattage and multiplying it by the number of each appliance that an individual household possesses to provide the total wattage of each appliance. The matrix was named matrix M1, and each appliance was assigned A1 to A12 to define the first to twelve rows of the matrix from 12 rows and 1 column.

Table 1: Appliance and power units

matrix M1				
Household Appliances	**Appliance Type**	**Number**	**Power Rating**	**Total Power**
A1	Energy saver light	7	15	105
A2	Refrigerator	1	200	200
A3	Straightening iron	1	1200	1200
A4	Geyser (Electric)	1	1500	1500
A5	Radio	1	15	15
A6	TV	1	150	150
A7	Stove	1	1500	1500
A8	phone charger	4	5	20
A9	Washing Machine	1	1000	1000
A10	Laptop	1	100	100
A11	Security Light	1	32	32
A12	Phantom loads and other base loads	1	200	200
	TOTAL ALL-CONNECTED POWER			6022

The second matrix, named matrix 2, was assigned 12 rows to represent 12 hours, and the columns were assigned A1 to A12 to represent 12 columns, as illustrated in Table 2. Hence, this 12 by 12 matrix defined the percentage usage of each appliance per hour. The percentage usage at the end of 12 hours marks the total number of hours each appliance used the electricity.

Table 2: Energy consumption matrix

matrix m2	**Energy saver light**	**Refrigerator**	**Straightening iron**	**Geyser (Electric)**	**Radio**	**TV**	**Stove**	**phone charger**	**Washing Machine**	**Laptop**	**Security Light**	**Phantom loads and other base loads**
Time (hrs)	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
1	1	0.3	0	0	0	0	0	0.5	0	0	1	0
2	1	0.3	0	0	0	0	0	0.5	0	0	1	0
3	1	0.3	0	0	0	0	0	0.5	0	0	1	0
4	1	0.3	0	0	0	0	0	0.5	0	0	1	0
5	1	0.3	0	0.1	0	0.5	0	0.5	0.2	0	1	0
6	0	1	0	0.1	0.5	0.5	0.2	0.5	0.1	0	0.5	0
7	0	1	0	0.1	0.5	0.5	0.1	0.5	0.1	0	0	0
8	0	1	0	0	0.5	0.5	0.1	0	0	0	0	0
9	0	1	0	0	0.8	0.5	0	0	0	1	0	0
10	0	1	0	0	0.8	0.5	0	0	0	1	0	0
11	0	1	0	0	0.8	0.5	0	0	0	1	0	0
12	0	1	0	0	0.8	0.5	0	0	0	1	0	0
13	0	1	0.1	0.1	1	0.1	0	0	0	1	0	0
14	0	1	0	0	0.8	0.5	0	1	0	1	0	0
15	0	1	0	0	0.4	0.5	0	1	0	1	0	0

16	0	1	0	0	0.4	0.5	0.1	1	0	0	0	0
17	0	1	0	0	0.8	0.5	0.1	1	0	0	0	0
18	1	0.5	0	0	0.8	0.5	0.2	1	0	0	1	0
19	1	0.5	0	0.3	1	0.3	0.2	1	0	0	1	0
20	1	0.5	0	0.1	1	0.1	0.1	0	0	0	1	1
21	1	0.5	0	0	1	0	0.1	0	0	0	1	0
22	1	0.3	0	0	1	0	0	0	0	0	1	0
23	0.167	0.3	0	0	0	0	0	0	0	0	1	0
24	0.167	0.3	0	0	0	0	0	0	0	0	1	0
	10.334	16.4	0.1	0.8	12.9	7	1.2	9.5	0.4	7	12.5	1

Then, both matrix 2 and matrix 1 are the matrices of the 12 by 12 and 12 by 1; their multiplication forms the matrix of 12 by 1. This means that when multiplying matrix 2 by matrix 1, the solution is matrix 3 as seen in Table 3, which is the MASOWE load profile. These are the matrices from Dlamini and Cromieres for implementing peak load reduction algorithms for household electrical appliance studies to develop load profiles referenced in the literature section above [44]. Additionally, Table 3 individual power consumption load profile is indicated by column 3 in power (kW), whereas column 4 displays the load profile for the community symbolised by community power (kW).

Table 3: Load profile for MASOWE

MATRIX M3 - M2 X M1			
Time	Power (W)	Power (kW)	community power (kW)
0	207	0.21	209.07
1	207	0.21	209.07
2	207	0.21	209.07
3	207	0.21	209.07
4	632	0.63	638.32
5	858.5	0.86	867.09
6	692.5	0.69	699.43
7	432.5	0.43	436.83
8	387	0.39	390.87

9	387	0.39	390.87
10	387	0.39	390.87
11	387	0.39	390.87
12	600	0.60	606.00
13	407	0.41	411.07
14	401	0.40	405.01
15	451	0.45	455.51
16	457	0.46	461.57
17	644	0.64	650.44
18	1067	1.07	1077.67
19	767	0.77	774.67
20	402	0.40	406.02
21	212	0.21	214.12
22	109.535	0.11	110.63
23	109.535	0.11	110.63
	10619	**10.62**	**10724.76**

The household electricity consumption is reflected in *Figure 19*, showing the peak electricity demand at 6 am and 7 pm at 0.86 kW and 1.07 kW, respectively. This pattern shows the same design displayed by the Lesotho Electricity Company (LEC) in *Figure 8* above with double peak demands to the Lesotho Load profile, remote rural African and Botswana load profiles.

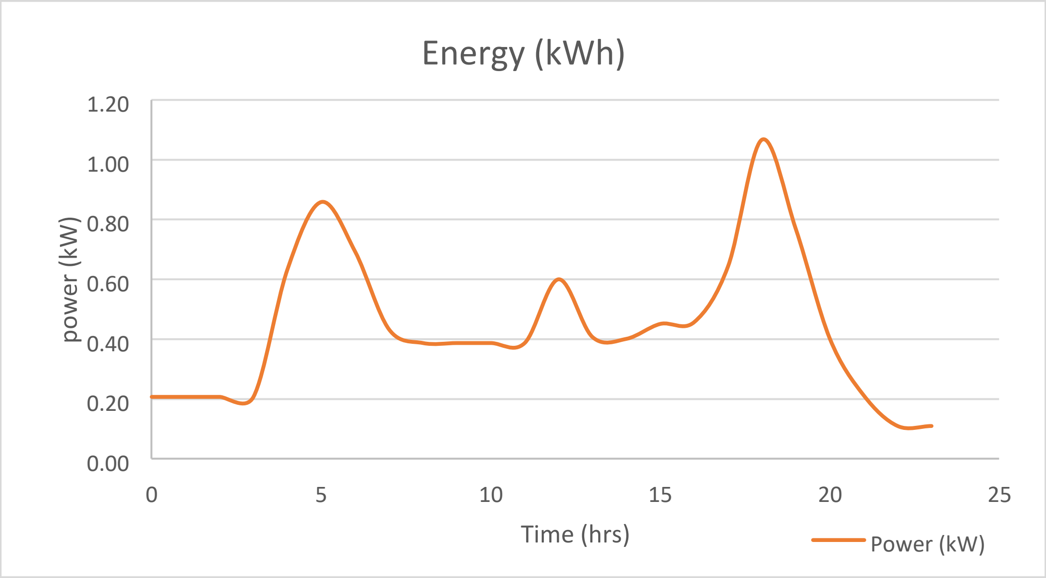


Figure 19: Household load profile

The seasonal load profile in *Figure 20* shows that the maximum energy consumption for the MASOWE residential sector is in the June winter month when the minimum temperatures are below zero degrees Celsius for space heating. The other period shows high summer energy consumption during December when the residents actively participate in entertainment and are on leave from the usual working environment. The yearly load profile in *Figure* 21 also shows that throughout the year, most of the energy is used at 7 pm, with the reddish scale around 1 kW, followed by other peak humps at 6 am showing the consumption of 0.86 kW.

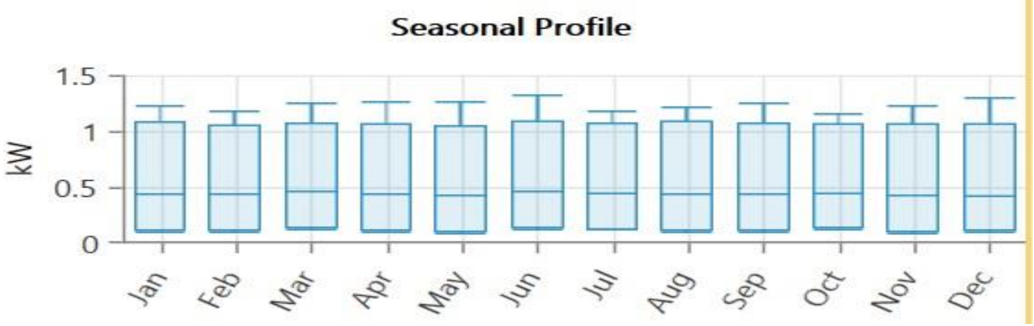


Figure 20: Seasonal profile

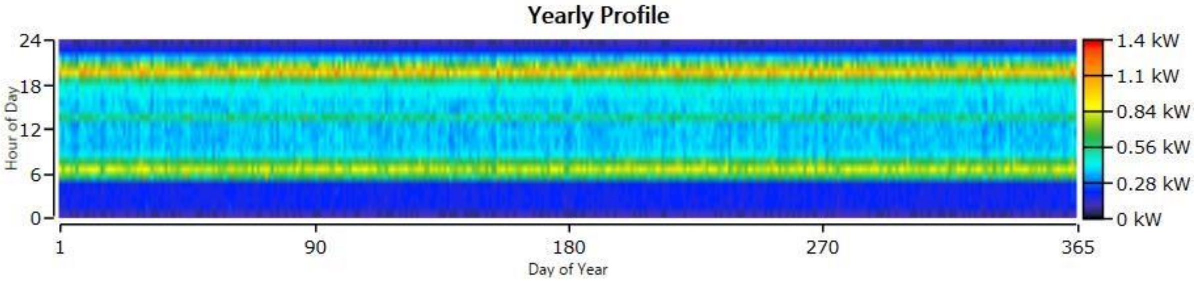


Figure 21: Yearly profile

The average electricity consumption of the MASOWE community is demonstrated in Figure 22, with the maximum demand at 6 am and 7 pm at 867.00 kW and 1,077.67 kW, respectively. This pattern shows the same design displayed by the Lesotho Electricity Company (LEC) in *Figure 8* above with three peak demands but slightly different from the South African load profile. This method of making reference to similar patterns and double peak load profiles from the African region accrues from the Prinsloo et al. research on scoping load profiles [43].

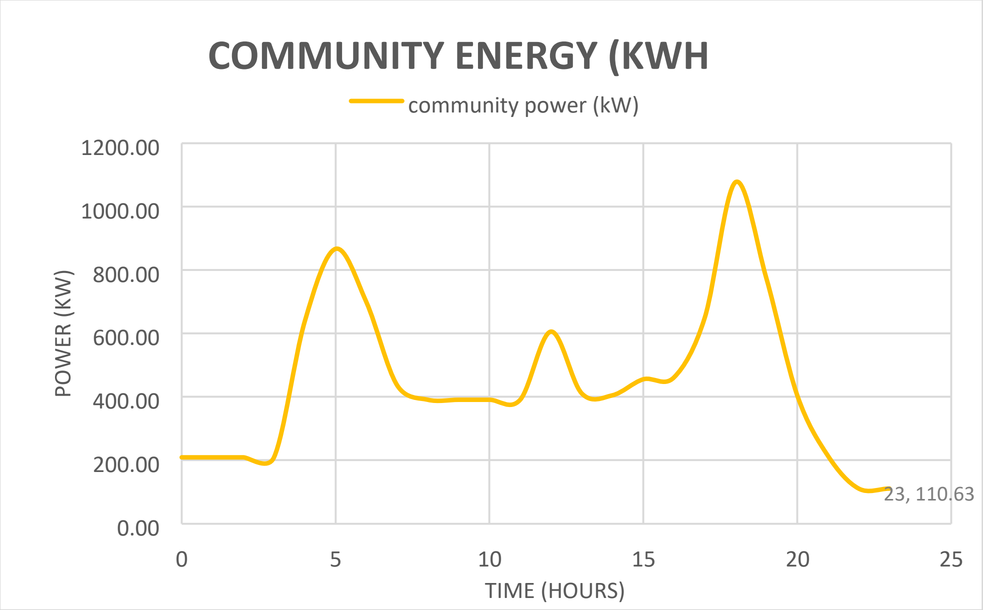


Figure 22: MASOWE community load profile

3.4 Net Metering Method

The power production shown in *Figure 23* demonstrates that solar power production can satisfy the demand except for the winter months when the power demand is more than the production from the PV systems. As a result, more power will be purchased from the grid during winter to meet the demand [60]. This will occur because the grid sales, which account for the excess electricity from the solar PV sold to the grid, are minimal during the day under the typical energy production scenario. The study analyses the amount of energy required to meet the electricity demand, especially in the winter season, where the solar radiation is low, to ensure energy security throughout the year.

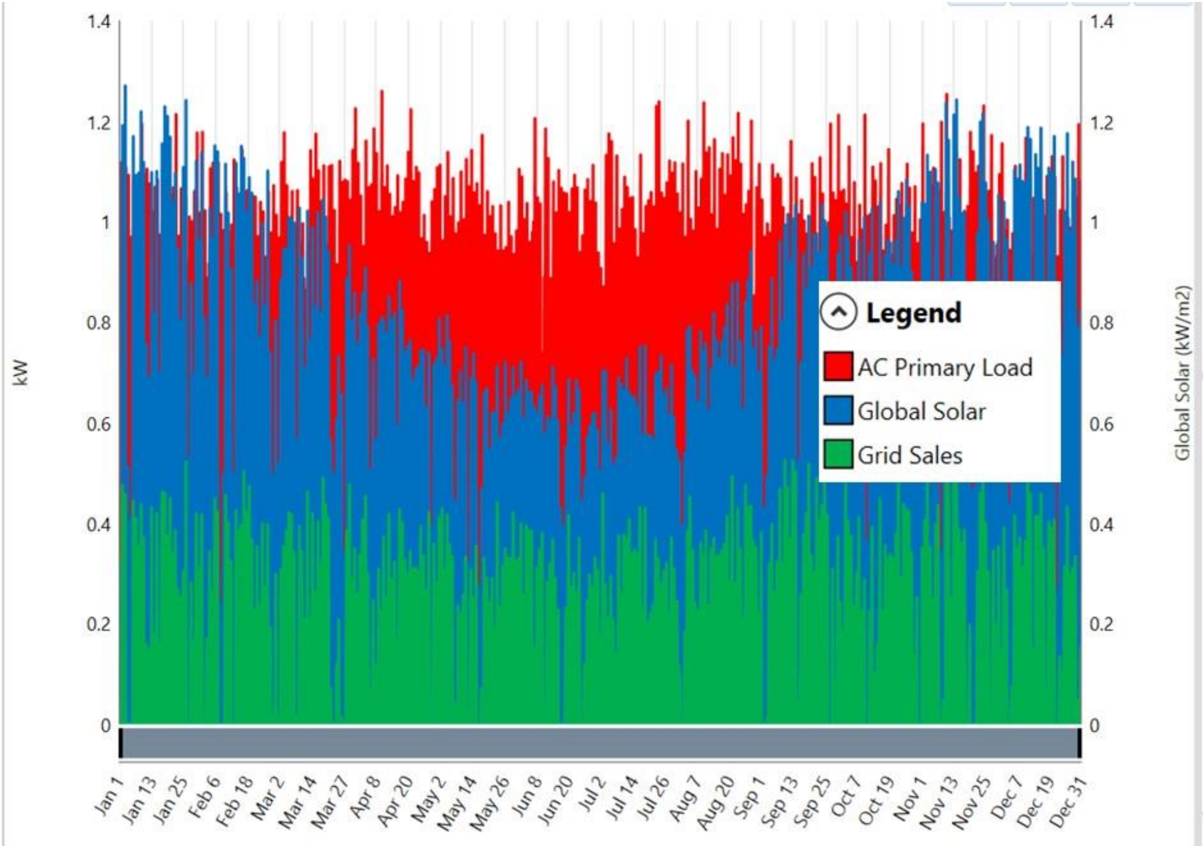


Figure 23: Yearly load and power production

The study adopted the Koumparou *et al*. method, shown in *Figure 13*. The net metering process to assess the household consumption, solar PV energy production to the grid and the energy from the grid when there is no solar radiation was also used [54]. HOMER Pro performs all these processes of the adapted model and provides the amount of energy purchased from the grid, and how much excess energy from the solar PV power production is sold to the grid.

3.4.2 HOMER Pro Schematic Diagram

For this study, the schematic diagram in *Figure 24* provides the optimised solar hybrid system with the electricity load, solar panels and converter. The sizing of the electricity load and the solar system is essential to find the amount of electricity that MASOWE requires for net metering system development and policy enforcement. The schematic diagram of HOMER Pro net metering systems also shows the electricity load with power supply from both the Grid and PV system for an electricity load of 10.45kWh/day and peak energy demand of 1.26kW. However, several studies have used the same model to assess net metering possibilities in countries that include Abu Dhabi [55]. Therefore, the current study used a similar schematic diagram to develop and analyse the MASOWE net metering system.

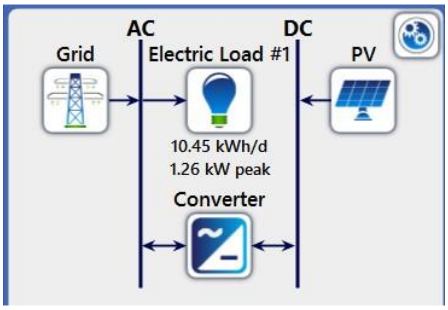
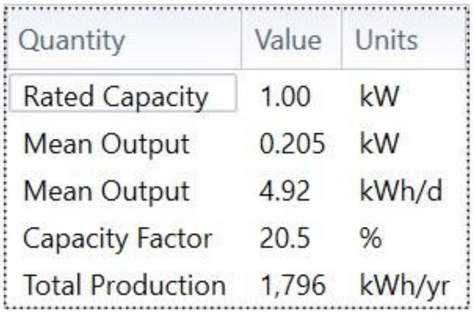


Figure 24: Solar hybrid schematic

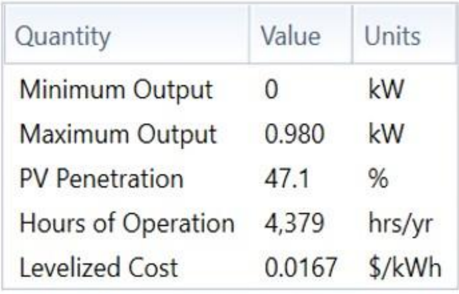
3.4.3 Solar PV panel

The solar panel used for this study is the generic flat plate of 1kW rated capacity. The solar panel arrays in *Figure 25* form the system with a mean output of 4.92kWh/d and a capacity factor of 20.5%. The solar PV penetration in Figure 26 accounts for 47.1% and operates for 4,379hrs/yr. This array of solar panels costs $476.38, a replacement cost of $300.00 after 25 years and an operation and maintenance cost of $10.00/yr.



Quantity	Value	Units
Rated Capacity	1.00	kW
Mean Output	0.205	kW
Mean Output	4.92	kWh/d
Capacity Factor	20.5	%
Total Production	1,796	kWh/yr

Figure 25: Solar Capacity

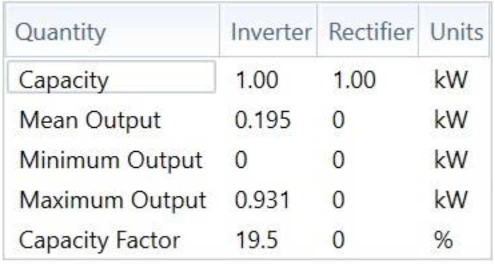


Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	0.980	kW
PV Penetration	47.1	%
Hours of Operation	4,379	hrs/yr
Levelized Cost	0.0167	$/kWh

Figure 26: Solar output and fraction in the hybrid system

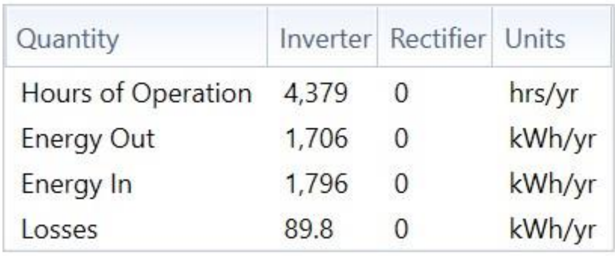
3.4.4 Solar Inverter

The inverter in *Figure 27*, which was used in this study, is the generic system converter with a capacity of 1kW. The mean output for this system in *Figure 28* is 0.195kW; the maximum output is 0,931kW, while its output is 1,706 kWh/yr. The selected solar inverter costs $300.00, and its replacement costs $300.00 after 15 years. The efficiency capacity of this inverter is 95%, and the capacity factor is 19.5%. The capacity factor is the actual generation of the system compared to the maximum power generation of the given time without any interruption [61].



Quantity	Inverter	Rectifier	Units
Capacity	1.00	1.00	kW
Mean Output	0.195	0	kW
Minimum Output	0	0	kW
Maximum Output	0.931	0	kW
Capacity Factor	19.5	0	%

Figure 27: Inverter capacity



Quantity	Inverter	Rectifier	Units
Hours of Operation	4,379	0	hrs/yr
Energy Out	1,706	0	kWh/yr
Energy In	1,796	0	kWh/yr
Losses	89.8	0	kWh/yr

Figure 28: Inverter Energy output

3.4.5 Techno-Economic Evaluation

The testing of net metering occurs when households produce electricity from solar PV systems for family energy demand. However, in the absence of solar radiation, the household gets the power from the utility company grid electricity during the night. Furthermore, the excess produced from the solar PV system is transmitted to the grid to recompense the amount of electricity that the household utilises at night. Five scenarios were performed to find the most economically viable model to achieve the possible net metering system for Lesotho.

The first three scenarios were for the household solar energy consumption from solar PV and the amount of energy purchased from the grid while the excess produced was sold to the grid to lower the cost of electricity.

Therefore, the household net metering analysis is as follows:

a. The first case is when solar power production is as usual, with no increment of the solar panels.
b. The second case is when the battery is introduced to the system.

c. The third case is when the solar PV is increased to the maximum capacity such that the energy purchased from the grid when there is no radiation is balanced by the access energy sold to the grid during the day.

The second two cases are for the community mini-grid net metering assessment:

d. The first case is the amount of solar PV energy required by the community to meet the demand compensated by the grid; at times, there is no radiation.

e. The second case is the sizing of the solar PV system required such that excess solar power production sales to the grid balance the purchases from the grid when there is no solar radiation and at night.

3.5 Calculation of Net Metering Cost Benefits

The net metering economic analysis is formulated based on the energy sales against the purchases to retrieve the economic indicators like LCOE, NPC and others. The section provides the methodology used to determine the cost-benefit analysis. The computation of the Net Present Cost (NPC), Simple Payback Period (SPP), Internal Rate of Return (IRR), and Profitability Index (PI) evaluates the economic and profitability of PV systems [62].

3.5.1 Energy Sales

The energy cost transaction was computed to determine how much electricity was purchased from the grid at night without solar radiation and to find how much excess electricity was sold to the grid during the day. The aim was to determine whether increasing or decreasing the tariff cost of $0.013 from Lesotho Electricity Company (LEC) is viable.

3.5.2 Cost-Benefit Analysis

The study used the cost-benefit analysis to analyse the cost against the household solar PV system's profit. The same method was used by Jia *et al*. to assess the effectiveness of net metering subsidies of the household distributed PV system [52]. The optimised results from HOMER provide the Least Cost of Energy (LCOE) for the solar PV system to provide the benefit of net metering. The benefit is based on the government's subsidies to the low-carbon solar PV system power generation to the MASOWE residents and the power sold to the grid. However, this study is required to benefit households by getting net zero bills on energy consumption.

3.6 Economic Feasibility Analysis

The Techno-Economic analysis requires the analysis of the LCOE, IRR and NPC [63]. Hence, the study used the HOMER Pro to analyse the net metering potential for the MASOWE residential sector to find the LCOE, IRR and NPC and assess the viability of the MASOWE residence solar PV net metering. Moreover, the study performed the sizing of the solar panels, inverter, bi-directional metre and current battery costs to find their technical and economic viability. In addition, the fixed costs (transmission and distribution costs) were used as the input for the HOMER Pro to model the optimised MASOWE residential area load profile results against the solar sources and economic factors. Abdulkarim showed that six factors that influence solar economics have a 25-year system life period, including solar module efficiency [63].

3.6.2 Sensitivity Analysis

The sensitivity analysis takes care of the uncertainty in the solar using the HOMER Pro sensitivity function and the search space of the parameters [58]. Under certain particular conditions, this modelling analyses how various values of a collection of independent variables affect the dependent variables. As the dependent variable in this instance, the analysis looks for the smallest feasible difference between the buying and selling processes. Therefore, a range of values for the Lesotho power unit cost, around US$ 0.13/kW, is chosen and evaluated at intervals of 0.05 above and below US $0.13/kW. The sensitivity applied in this study is the sell-back rate of $0.10/kWh, $0.12/kWh, $0,135/kWh, $0.14/kWh, $0.15/kWh and $0.16/kWh.

3.6.3 The Grid

The HOMER Pro software uses the grid as the benchmark to perform technical and financial analysis of the solar PV hybrid system [60]. The study reflected the amount of energy avoided and how much the cost was saved against the normal operation of the fixed tariffs by the LEC. The grid power price is $0.13kWh (M1.94/kWh), and the sell-back price to the grid is $0.10/kWh. The grid power capacity is 1.4kW per household.

3.6.4 HOMER Economic Equations

The HOMER power tool provides a fast and precise technical and economic analysis of hybrid power generation [64]. The software also assists in finding the optimum solution considering the LCOE and NPC installation, replacement, repair and lifetime. The HOMER Pro also uses the interest and inflation rates to simulate the optimum LCOE and the NPC. The LCOE and NPC determine the solar PV system's viability for Net Metering and provide the investor or the government with the option to invest in this solar system.

3.6.5 Cost-Effectiveness Analysis

The system simulates the optimal distributed PV systems to obtain the Total NPC. In this regard, the NPC provides a lifetime net present cost that entails the investment, replacement and operation costs [52]. The HOMER Pro, with input resources like solar panels, inverter, or converter cost and lifetime, analyses cash flow and economic factors.

3.6.6 Comparison of the HOMER Pro Results with and without Net Metering

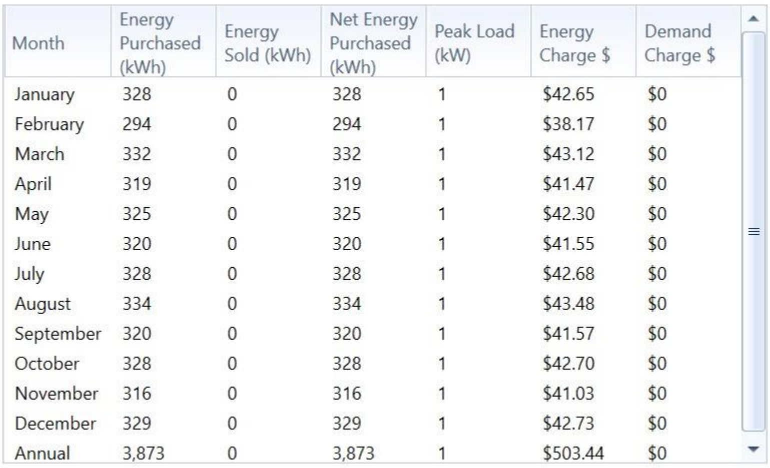
The study compares different models to analyse possible suitable models for net metering in Lesotho. Designing and modelling the grid-connected hybrid microgrid system using net metering requires analysis of technical, environmental and economic parameters [57]. Therefore, the study compared the optimised grid power supply results without net metering and the net metering results. The study found the optimum PV system with the desired Net Present Cost (NPC), Internal Rate of Return (IRR) and seasonal period. The study on designing and modelling a grid-connected PV-WT hybrid microgrid system using a net metering facility compares grid systems without net metering with net metering system technical and economic analysis [57]. Shaikh *et al*. [57] compare different models without and others with metering to find the economic feasibility of net metering in Lesotho. Therefore, the study followed the same analysis of two proposed work grid-connected PV-WT hybrid microgrid system strategies using the net metering facility as shown in *Figure 13* above [57].

3.7 Avoided Cost of Energy

The research provides the cost that can be avoided if the net metering system is implemented to improve accessibility and demand-supply electricity satisfaction. This cost will be avoided during the day when Solar Power covers the consumer electricity demand. It reflects the amount of energy from the solar PV system consumed to avoid the energy costs from the grid. The avoided cost is the net cost of energy when electricity consumption is from the grid minus the net cost of energy when solar power is added to the grid for power supply. Therefore, the area for the curve under both the demand and production profiles represents avoided energy costs.

The HOMER Pro model input for the model is the 9.62% discount rate and 9.2% inflation rate for the project lifetime of 25 years. The grid power price is $0.13/kWh, and the grid sellback selected by the model from the sensitive value list is $0.10/kWh. Solar panels cost $476.38/kW, $300.00/kW for maintenance and 10/kW/Year. The inverter cost is $300.00/kW, while the maintenance cost is $300.00/kW. These were the inputs to the HOMER Pro model, which calculated the monthly energy purchased, energy sold, net energy purchased, peak load, energy charge and demand charge, as reflected in *Figure 29*. However, the demand charges were $0.00. The calculations of avoided costs of energy under the net metering system are as follows:

i. Subtract net energy charges for the on-grid solar PV hybrid system shown in *Figure 30* from net energy charges of the grid power system without solar energy in *Figure 29*.
ii. Subtract on grid doubled solar PV on grid systems net energy charges as seen in *Figure 31* from the net energy charges of the grid without solar PV energy *Figure 29*.

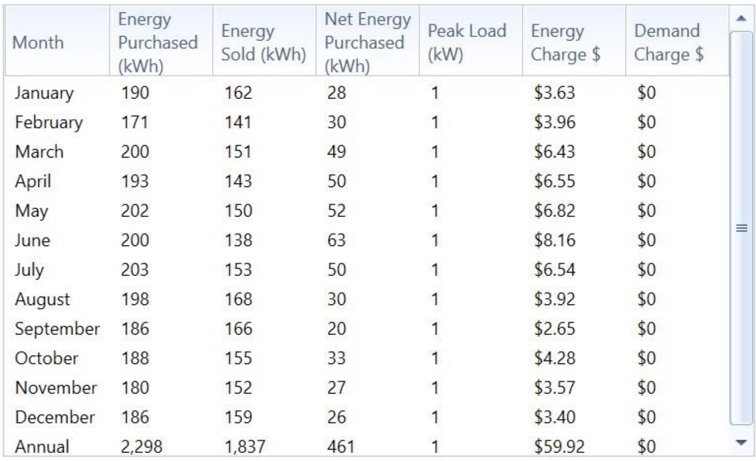


Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
January	328	0	328	1	$42.65	$0
February	294	0	294	1	$38.17	$0
March	332	0	332	1	$43.12	$0
April	319	0	319	1	$41.47	$0
May	325	0	325	1	$42.30	$0
June	320	0	320	1	$41.55	$0
July	328	0	328	1	$42.68	$0
August	334	0	334	1	$43.48	$0
September	320	0	320	1	$41.57	$0
October	328	0	328	1	$42.70	$0
November	316	0	316	1	$41.03	$0
December	329	0	329	1	$42.73	$0
Annual	3,873	0	3,873	1	$503.44	$0

Figure 29: HOMER Electricity charges grid only

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
January	216	38	178	1	$23.14	$0
February	194	32	162	1	$21.07	$0
March	223	33	191	1	$24.78	$0
April	214	30	185	1	$24.01	$0
May	220	31	189	1	$24.56	$0
June	219	28	191	1	$24.85	$0
July	221	31	189	1	$24.61	$0
August	219	37	182	1	$23.70	$0
September	209	39	170	1	$22.11	$0
October	213	32	181	1	$23.49	$0
November	207	35	172	1	$22.30	$0
December	212	34	177	1	$23.06	$0
Annual	2,568	401	2,167	1	$281.68	$0

Figure 30: Homer solar on grid electricity charges



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
January	190	162	28	1	$3.63	$0
February	171	141	30	1	$3.96	$0
March	200	151	49	1	$6.43	$0
April	193	143	50	1	$6.55	$0
May	202	150	52	1	$6.82	$0
June	200	138	63	1	$8.16	$0
July	203	153	50	1	$6.54	$0
August	198	168	30	1	$3.92	$0
September	186	166	20	1	$2.65	$0
October	188	155	33	1	$4.28	$0
November	180	152	27	1	$3.57	$0
December	186	159	26	1	$3.40	$0
Annual	2,298	1,837	461	1	$59.92	$0

Figure 31: HOMER Pro double on-grid solar power hybrid net electricity sales

3.8 Net Metering Policy Guide Methodology

The Net Metering policy has to follow the Lesotho National Energy policy, which encourages the adoption of net metering as a renewable energy promotion strategy [7]. The study also assesses the self-consumption and storage net metering scheme because of the low economic and risk reduction to the Lesotho utility company (LEC). Moreover, the study focused on the lessons learned from other countries' net metering schemes, focusing more on the SADC region. The SADC region is mandated to promote net metering to attract private investment in renewable energy [65]. It assesses the effect of solar PV and hydropower plants on the environment. Therefore, amongst the net metering schemes described in the literature review, the study selected an energy restriction framework for both individuals and the community granularity. This net metering scheme was analysed technically and financially to find the option of implementing it without causing economic or technical harm to the utility grid and country.

Therefore, the current study follows the same model to compare the HOMER Pro and TechnoEconomic models' NPC, IRR, LCOE and payback period to determine whether net metering can be viable for the MASOWE residential sector. The study's results also reflect the technical and economic aspects of the net metering for the MASOWE households and community of 1010 residents.

Finally, this chapter provides the technical and economic feasibility analysis methods. These methods are based on Prinsloo's [43] scoping exercise to determine the load profile and Koumparou et al.'s method [54] analysis to determine net metering system implication to the economy of Lesotho. The avoided cost of energy, economic and cost-benefit analysis methodologies also guide how the net metering feasibility can be determined.

CHAPTER FOUR

SIMULATION RESULTS AND ANALYSIS

4.0 Introduction

The research comprehensively analyses the net metering for the MASOWE residential sector in Lesotho. The study also provides the basis grid electricity consumption analysis, rooftop solar PV net metering without a battery and a similar analysis with the battery introduced. This section compares the energy distributed by the Lesotho Electricity Company (LEC) without net metering against solar PV net metering power supply connected to the main grid for the typical MASOWE residential household's electricity consumption. The study further assessed net metering's economic feasibility.

4.1 Technical Analysis

This section provides the technical implications of solar PV net metering systems to the MASOWE community. It also provides the modelling and assessment of the technical possibility of implementing solar PV net metering for the MASOWE residents.

4.1.1 Results for the solar energy penetration

The annual energy penetration for solar PV systems shown in *Figure 32* is most at mid-day for most days of the year. The solar PV power output is more than 0.80 kW, while hours after 6 pm and before 6 am have no solar power output because the radiation during those hours is not available to reach the solar panel.

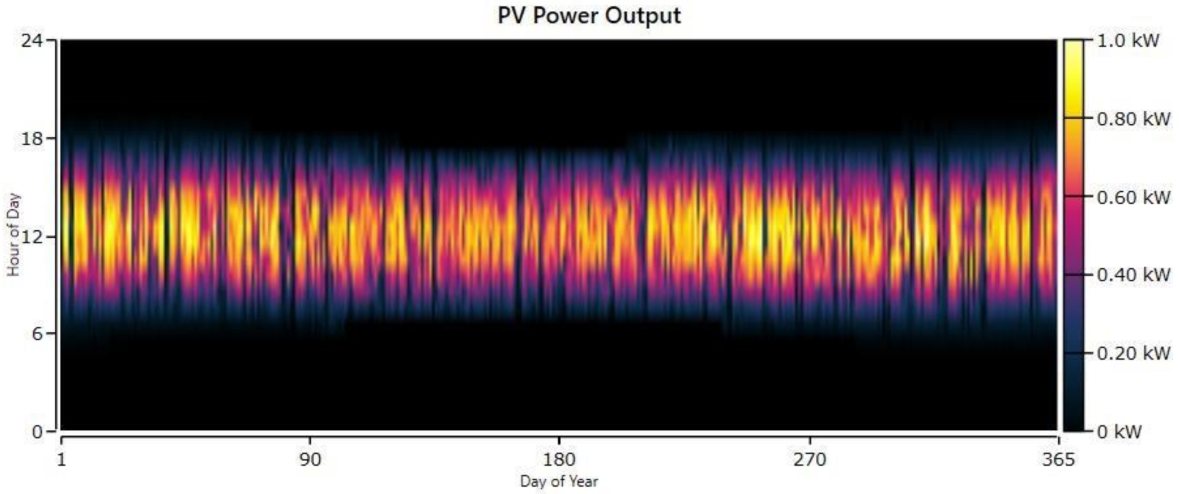


Figure 32: Annual energy penetration of solar PV system

4.1.2 Operation of Bi-Directional Converter

The bi-directional converter in *Figure 33* feeds the electricity to the Lesotho Electricity Company's (LEC) main grid during the day when there is excess solar power production. During the night, the converter in Figure 34 draws electricity from a utility company to supply the households [41]. The peak energy supply from the converter is at 6 pm and 7 pm in the evening when the household demand for electricity supply is high. The converter cuts off the utility supply during the days when adequate solar energy supply is achieved [41]. The lower cut is reached from 12 noon to 2 pm. This daytime peak energy consumption occurs at lunch hour when some households are at home for the next day's work and school preparations, and the radiation from the sun is at maximum. The scale also shows the reddish colour at 1 pm, showing the solar converter's maximum functioning at around 0.69 kW.

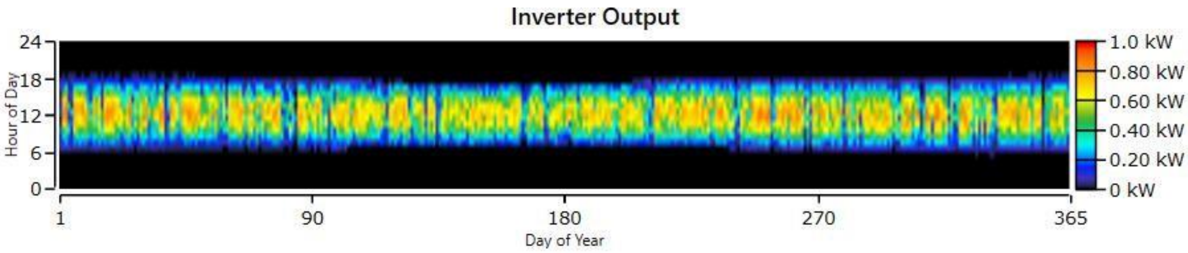


Figure 33: Yearly energy output of the bi-directional converter

4.1.3 Energy Dawn from the Utility Grid

The models in Figure 34 and Figure 35 show that the net metering systems require the MASOWE household to purchase electricity from the main utility grid in the morning, around 6 am and mainly in the evening, around 7 pm. The model shows a similar net metering system by other researchers, such as Yadav *et al*. on technical and financial assessment of a gridconnected solar PV net metering system for residential communities [66]. The HOMER Pro model simulates the purchases and sales using the prices of the solar panels, inverter and the grid system provided as the input to the model.

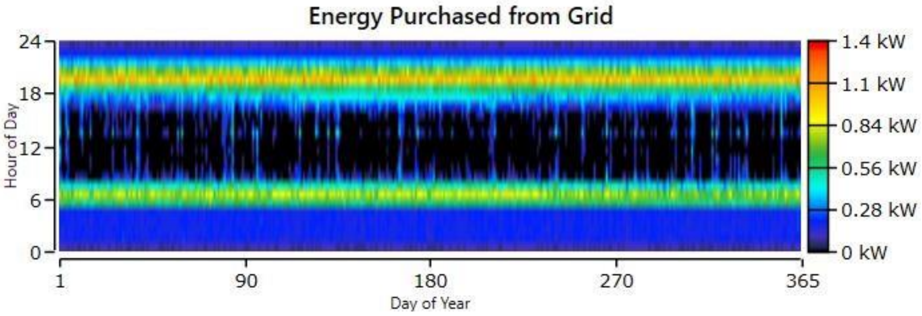


Figure 34: Yearly energy purchased from the utility grid

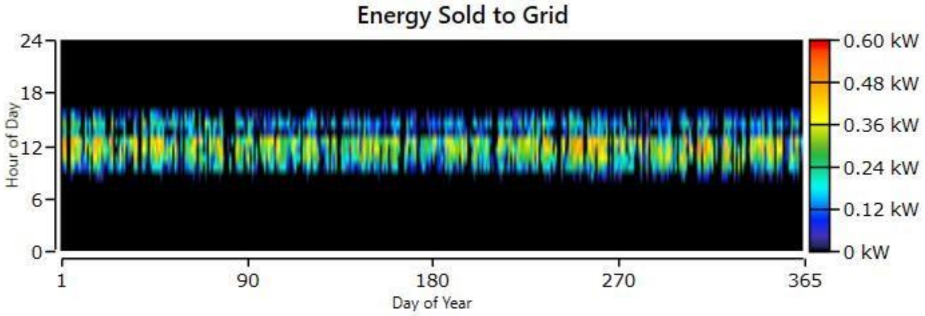


Figure 35: Yearly energy sold to the grid

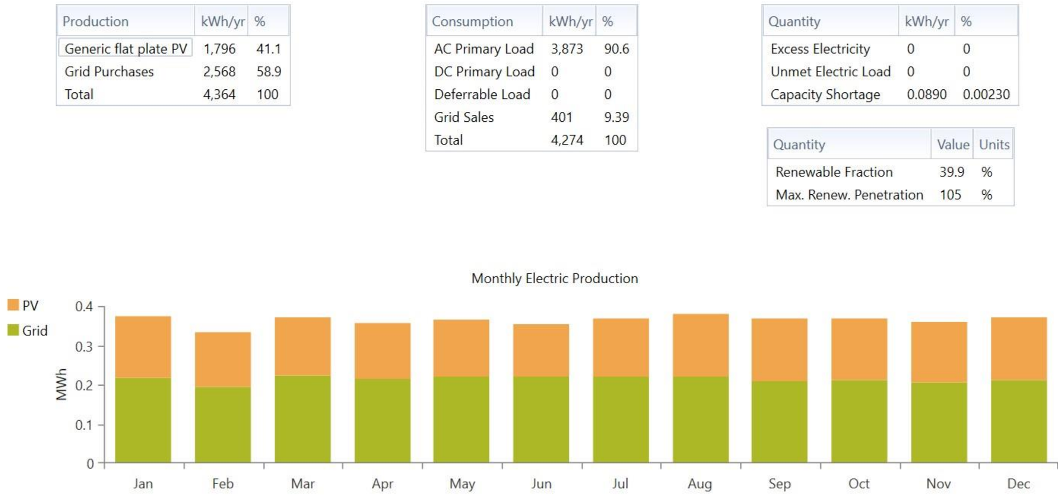
4.2 Net Metering Analysis

Net metering provides the amount of energy produced from solar PV for household consumption and the energy that the household consumes from the utility company, Lesotho Electricity Company (LEC) grid. The analysis follows the methods adopted by Alhamad and Razali et al. in comparing stand-alone and grid-connected roof-mounted PV solar systems' Net Metering [55], [67].

4.2.1 Household Normal Energy Consumption and Sales

The solar PV net metering system sizing in *Figure 36* below shows that the total energy produced for the household is 4,364 kWh/yr. However, solar PV can only provide 1,796 kW/yr (41.1%) while the energy purchased from the LEC grid is 2,568 kW/yr (58.9%). Therefore, the household energy consumption is 3,873 kW (90.6%) while only 401 kW (9.39 %) is sold to the LEC grid. The HOMER Pro further shows that with the monthly contribution of the LEC grid electricity and solar PV systems, more power is from the utility grid, providing results similar to other research, such as the Deshmukh on solar PV system modelling research [41]. Thus, 58.9% of energy is purchased under this model, while only 9.39% is sold to the grid.

This means the household pays more to the utility grid, than the sales made during the day from solar PV systems.



Production	kWh/yr	%
Generic flat plate PV	1,796	41.1
Grid Purchases	2,568	58.9
Total	4,364	100

Consumption	kWh/yr	%
AC Primary Load	3,873	90.6
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	401	9.39
Total	4,274	100

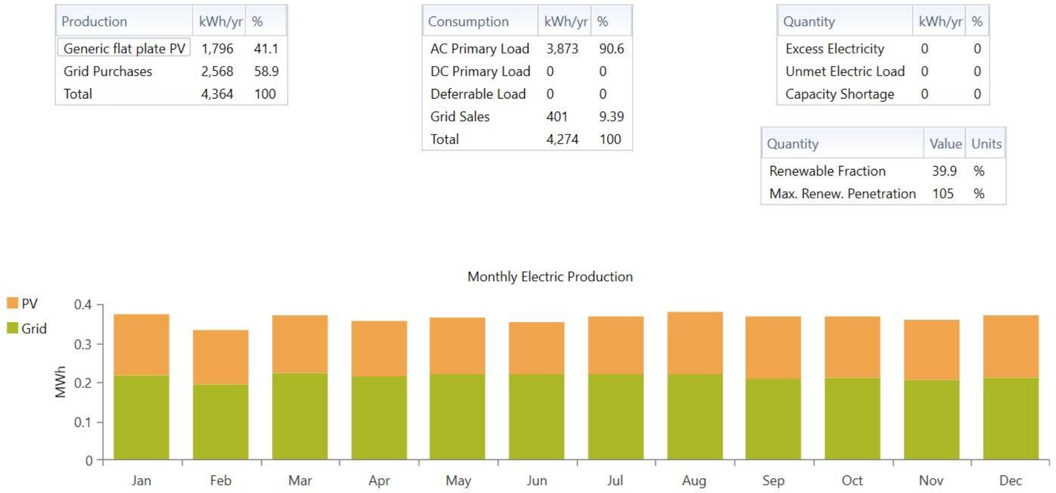
Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0.0890	0.00230

Quantity	Value	Units
Renewable Fraction	39.9	%
Max. Renew. Penetration	105	%

Figure 36: Household energy consumption and sales

4.2.2 Household Energy Consumption and Sales with Storage

In *Figure 37* below, House Energy Consumption and sales are simulated with the storage added to the solar PV system to boost solar power production. The results show that the total energy production after adding the storage remains unchanged at 4,364kW/yr. As a result, solar PV power production remains the same at 1,796kW (41.1%). The sales to the grid also remained the same at 401 kWh/yr (9.39%) as before the addition of the storage, while the Grid Purchases were at 2,568 kWh/yr (58.9%).



Production	kWh/yr	%
Generic flat plate PV	1,796	41.1
Grid Purchases	2,568	58.9
Total	4,364	100

Consumption	kWh/yr	%
AC Primary Load	3,873	90.6
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	401	9.39
Total	4,274	100

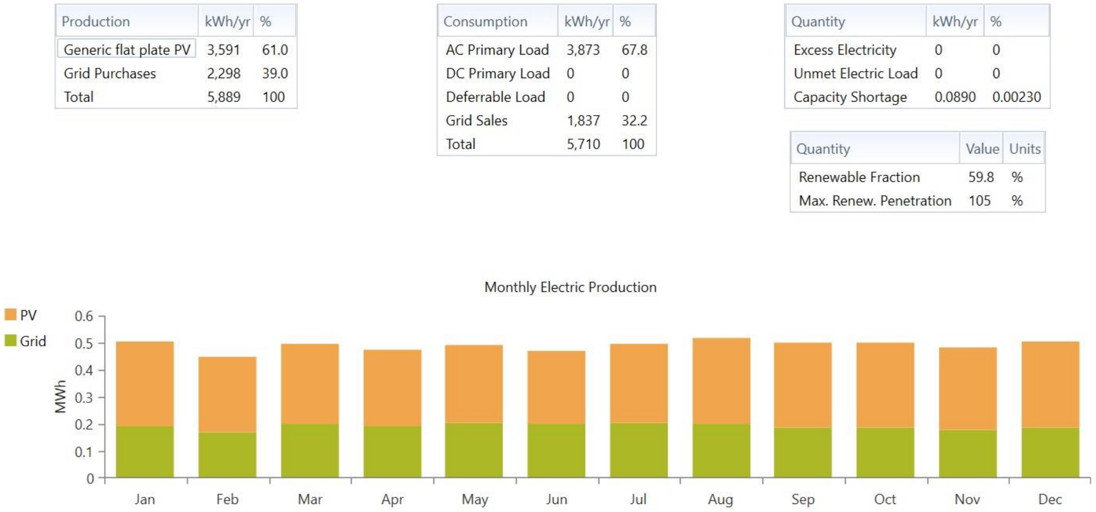
Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	39.9	%
Max. Renew. Penetration	105	%

Figure 37: Household consumption and sales with storage

4.2.3 Household Energy Consumption and Sales Doubled Solar Power

The scenario in *Figure 38* below shows an increase in solar PV power production to balance the consumption to attain the Levelized Cost of Energy (LCOE). The total energy production has increased from 4,364 kWh/yr to 5,889 kWh/yr. The energy production contribution from Solar PV has increased from 1,796 kW (41.1%) to 3,591 kWh/yr (61%), making only 19.9% (1,795 kWh/yr) of energy purchases from the grid. The primary load consumption is 3,873 kWh/yr (67.8%), which makes the grid sales 1,837 kWh/yr (32.2%). There is a significant increase in energy sales to the grid to increase compensation for the purchases made during the period without solar power generation.



Production	kWh/yr	%
Generic flat plate PV	3,591	61.0
Grid Purchases	2,298	39.0
Total	5,889	100

Consumption	kWh/yr	%
AC Primary Load	3,873	67.8
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	1,837	32.2
Total	5,710	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0.0890	0.00230

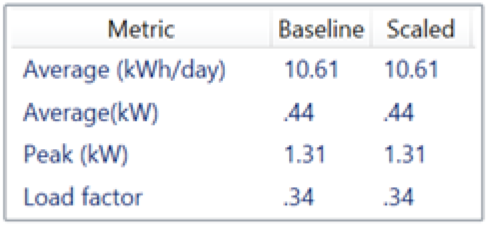
Quantity	Value	Units
Renewable Fraction	59.8	%
Max. Renew. Penetration	105	%

Figure 38: Doubled solar power household energy consumption and sales

On the contrary, these grid sales to reduce the grid purchases answer to the concept of net metering to reduce electricity purchases from the utility grid [8]. The grid purchases account for 39%, and the grid sales account for 32.2%, which makes the monthly household bills minimum. Therefore, according to Deshmukh and Singh, net metering requires optimised energy production and consumption, but to satisfy the criteria fully, the minimum LCOE has to be achieved [41].

4.2.4 System Performance

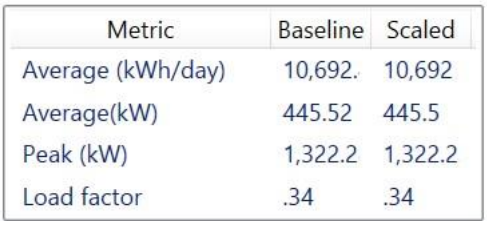
The capacity factor of a solar PV system compares the energy that the solar PV system produces against the system's maximum energy output [55]. This system has a capacity factor of 20.5% at the system converter and 20.5% at the generic flat plate solar panel. The current solar PV hybrid system reflected in *Figure 39* has a load factor of 34%, making the model load a good fit for solar PV sizing [68]. The load factor is high enough to indicate that the solar PV system uses energy efficiently, and it signifies the cheaper unit cost per kWh as it is near the peak value of the electricity load [69]. The average energy of the solar PV system is 10.61 kWh/day.
In comparison, the system's power is 0.44 kW on average and has a peak of 1.31 kW.



Metric	Baseline	Scaled
Average (kWh/day)	10.61	10.61
Average(kW)	.44	.44
Peak (kW)	1.31	1.31
Load factor	.34	.34

Figure 39: Solar PV power production

The average daily solar power output for the neighbourhood is 10,692 kWh/day in *Figure 40*, but the average annual power produced is 445.52 kW. The community system load factor is designed to be 34%, and the peak load is 1,322.2 kW.



Metric	Baseline	Scaled
Average (kWh/day)	10,692.	10,692
Average(kW)	445.52	445.5
Peak (kW)	1,322.2	1,322.2
Load factor	.34	.34

Figure 40: MASOWE community energy consumption

The load profile is the essential factor contributing to the behaviour of the energy cost, as increasing the load profile decreases the levelized cost of energy [70]. The peak load also helps design and model the technical feasibility of net metering to size the required model to meet the household demand [44].

This net metering study adopts the method by Koumparou et al. to compare daily energy consumption against night energy consumption for MASOWE households [54]. The study further determines the net-metering policy by comparing the daily behaviour of the total solar PV energy production against the resident's consumption of solar PV energy [15], [71], [72]. Therefore, the MASOWE household solar PV energy production analysis against consumption for the winter and summer seasons was analysed in *Figure 41* and *Figure 42* below, respectively.

The typical load profile balance is based on generation, consumption, grid energy purchases and sales. Generally, the winter load profile in *Figure 41* shows the area between the grid sales in green and the demand in red. This area is small while the area below the grid purchase in orange is large. This means that more electricity is purchased from the grid during winter to meet the demand. The lower energy sales from solar PV systems in winter are due to the lower solar radiation as shown by the global solar curve in *Figure 41* below. Furthermore, the number of winter workday hours is shorter from 6 am to 5 pm while during the summer months, it is from 5 am to 7 pm.

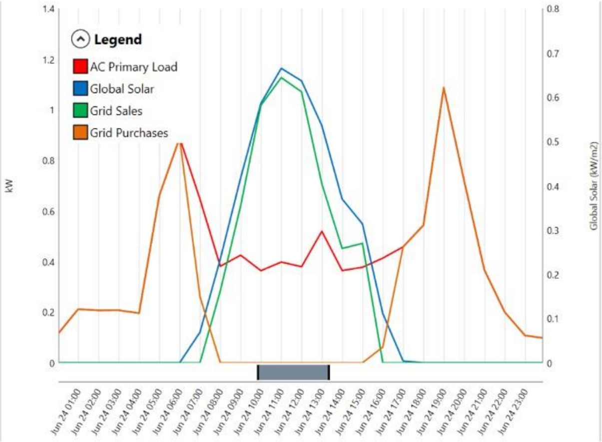


Figure 41 Winter profile

The graph *Figure 42* shows that the solar PV system starts power generation at 5 am and ends at 7 pm for the summer months. The sales to the grid start at 7 am and end at 5 pm while the grid purchase begins at 4 pm and ends at 8 am. Therefore, the workday consumption is less than the non-workday use of electricity. This is shown by the area under the grid purchase curve against the area between the red consumption graph and the orange electricity purchase graph. However, similar patterns of the grid purchase curves outside both sides of the global solar radiation graph show the area reflecting the MASOWE load profile consumption in the absence of solar power production. Therefore, for the summer month, the grid electricity sales plus the solar PV systems power generation demand a smaller amount of electricity purchases from the utility grid [72].

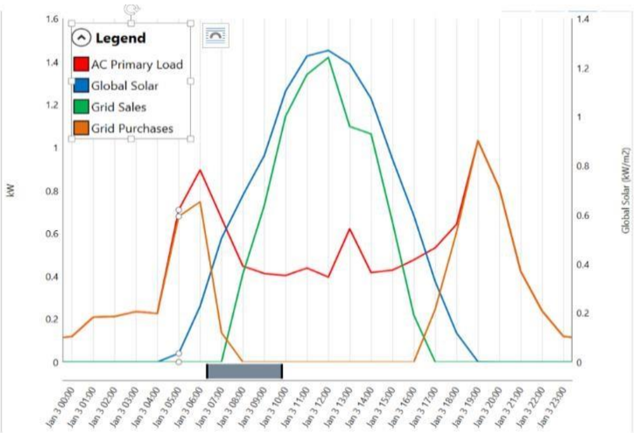
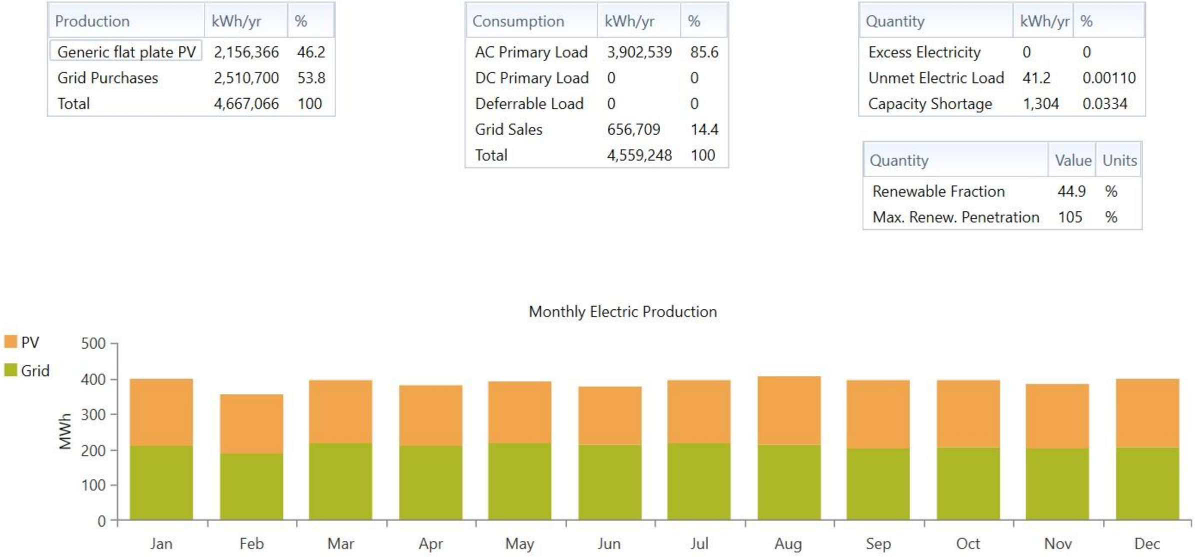


Figure 42: Summer profile

4.2.5 Community Consumption and Sales

The mini-grid access for MASOWE community solar PV sizing in *Figure 43* shows 2,156,366 kWh/yr (46.2%) energy production for 1010 households, while 2,510,700 kWh/yr (53.8%) is purchased from the utility grid. The total energy produced by this power system for this community is 39,767,218 kWh/yr. The total energy production is 4,667,066 kWh/yr, while the load that the community consumes is 3,902.539 kWh/yr (85.6%). This means that the system needs more electricity purchases of 53.8% from the LEC grid at night and fewer sales of 14.4% to the grid during the day. The monthly electricity production also shows that most energy production is through the grid throughout the year, while solar PV power accounts for the same portion.



Production	kWh/yr	%
Generic flat plate PV	2,156,366	46.2
Grid Purchases	2,510,700	53.8
Total	4,667,066	100

Consumption	kWh/yr	%
AC Primary Load	3,902,539	85.6
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	656,709	14.4
Total	4,559,248	100

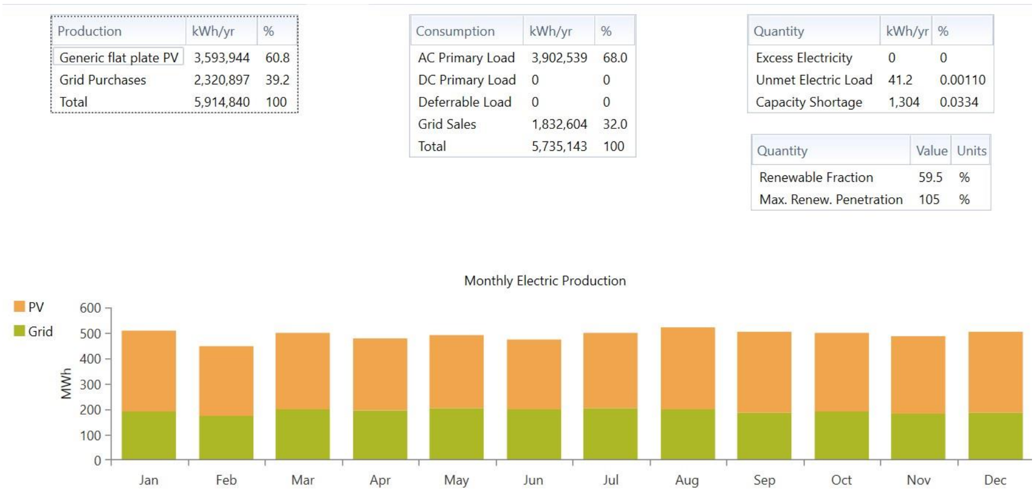
Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	41.2	0.00110
Capacity Shortage	1,304	0.0334

Quantity	Value	Units
Renewable Fraction	44.9	%
Max. Renew. Penetration	105	%

Figure 43: MASOWE community consumption and sales profile

4.2.6 Doubled Community Solar Energy Consumption and Sales

The net metering system in *Figure 44* satisfies the criteria of the optimised difference between energy production and consumption to achieve a minimum price per kWh [15], [28], [72]. This is because if the solar contribution is increased more than this level, the purchases and sales difference increases again, and the LCOE increases. The mini-grid produces a total power of 5,914,840 kWh/yr. The Solar PV contributes 3,593,944 kWh/yr (60.8%) while the LEC Grid purchases make 2,320,897 kWh/yr (39.2%). The primary load consumes 3,902,539 kWh/yr (68%), while the grid sales are 1,832,604 kWh/yr (32%). Therefore, the difference of 39.2% to 32% of the grid purchases and the grid sales is minimal, making the model viable for net metering. This reflects one of the net metering benefits of reducing the electricity bills to the prosumer or customer [73]. However, the requirement is to make the grid purchases more than grid sales to cover utility charges, such as utility wheeling costs.



Production	kWh/yr	%
Generic flat plate PV	3,593,944	60.8
Grid Purchases	2,320,897	39.2
Total	5,914,840	100

Consumption	kWh/yr	%
AC Primary Load	3,902,539	68.0
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	1,832,604	32.0
Total	5,735,143	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	41.2	0.00110
Capacity Shortage	1,304	0.0334

Quantity	Value	Units
Renewable Fraction	59.5	%
Max. Renew. Penetration	105	%

Figure 44: Double-sizing solar PV for MASOWE community

4.3 Cost-Benefit Analysis

The drop in the price of solar PV systems and the international treaties on the protection of the environment have caused the solar PV system to be more attractive for the power supply [25]. Therefore, the increase in the size of solar PV to the point where the grid purchases and grid sales are almost balanced is the most recommended criterion for the solar PV Net Metering system [71]. The desired solar PV net metering system in *Figure 45* reflects a few power purchases from the grid throughout the year. However, the excess grid electricity sales shown in green are mostly reserved and stored in the grid to be used when solar radiation is low in winter. The hybrid system fully absorbs the primary load throughout the year.

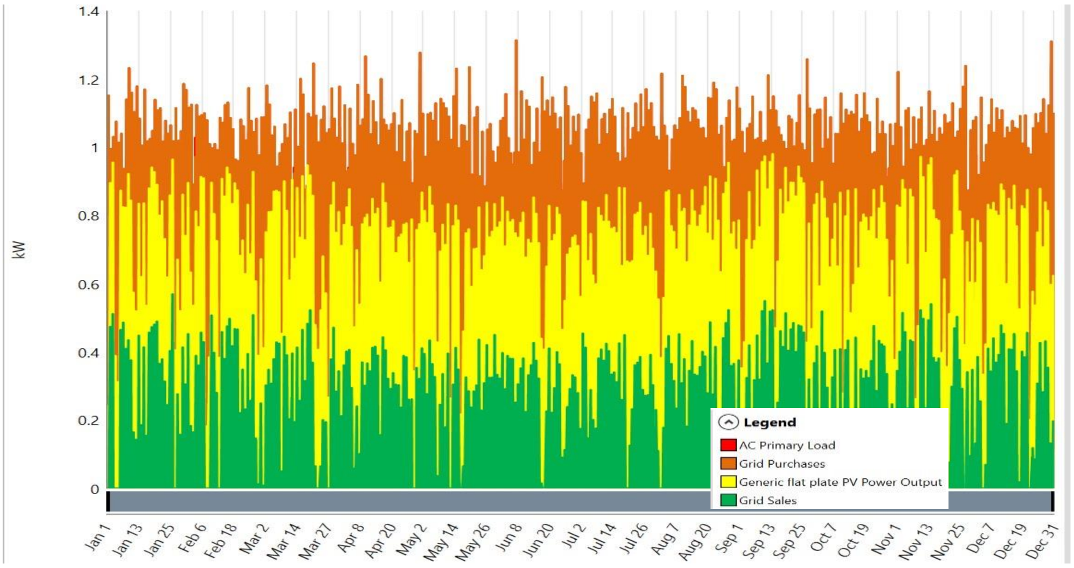


Figure 45: Yearly grid sales and purchases

4.4 Economic Analysis

The base system for the research is the grid-connected household without a solar PV system illustrated in *Table 4* below, which has a Net NPC of $11,978.00, operation and management (O&M) cost of $503.44/yr and LCOE of $0.13,/kWh. Adding a 1 kW solar PV system decreased the NPC to $7,909.45, O&M to $299.77 /yr and LCOE to $0.0778/kWh. The LCOE was reduced by $0.0522/kWh. When solar is added to the system, the minimisation of the LCOE makes solar PV power production more attractive than getting power from the grid [74]. The IRR is 27%, while the ROI is 22% for the system, with a payback period of 3.7 years.

As reflected in *Table 4*, the cost benefits show that when doubling the solar PV power to 2kW, the NPC decreases further to $3,838.88, and O&M costs drop to $96.09/yr. However, the LCOE also reduces to $0.02826/kWh significantly. This makes the system more attractive for the household than the first cases. This is because when the IRR increases to 27%, the ROI rises to 22%, and the payback period is a minimum of 3.7 years. Adding storage does not make any more major difference as storage remains insignificant [15], [75], [75], [76]. Therefore, further analysis will be based on the other two cases.

Furthermore, *Table 4* also shows the community solar PV mini-grid connected to the main grid. The solar PV hybrid NPC of $7,182.350.00 decreased to $3,923,607.00 as the number of solar panels increased. Moreover, the operation and management (O&M) cost of $262,721/yr also decreased to $99,648/yr. The capital cost required by this system is $262,721.00, resulting in an LCOE of $0.0662/kWh, an IRR of 27% and an ROI of 22% after 25 years. The system payback is just 3.7 years, which makes it attractive for investment, as highlighted by Hemapala and Jayasinghe of Sri Lanka’s net metering analysis [77].

As the solar PV system size increases, the difference between energy grid purchases and grid sales decreases NPV from $7,182,350.00 to $3,923,607.00, which reflects a $3,258,743.00 difference. This is similar to the previous case of single households and under the mini-grid net metering. Additionally, the LCOE in the same pattern reduces from $0.0662/kWh to $0.02875/kWh resulting in a $0.03745/kWh difference. The IRR and ROI also remain on a similar pattern of about 27% and 22% increase, respectively. The payback period was reduced to 3.7 years.

Table 4: Economic and Cost Benefits

		Household system sizing HOMER pro			community system sizing HOMER Pro		
Parameters	**Base**	**Household**	**Double PV**	**With storage**	**Base**	**Community system sizing**	**Double PV**
PV power		1 kW	2kW	1 kW		1, 200 kW	2, 000 kW
Inverter power		1 kW	2 kW	1 kW		1, 200 kW	2, 000 kW
NPC	$11,978.00	$7,909.45	$3,838.88	$7,908.00	$12.1M	$7,182,350.00	$3,923,607.00
initial capital	$0.00	$776.38	$1,553.00	$776.38	$0.00	$262,721.00	$1,552,760.00
O&M	503.44/yr	299.77/yr	$96.09/Yr	$299.77/yr	$507,330/yr	$262,721/yr	$99, 648/yr
LCOE	$0.13/kWh	$0.0778/kWh	$0.02826/kWh	$0.0778/kWh	0.13/kWh	$0.0662/kWh	$0.02875/kWh
IRR		27%	27%	27%		27%	27%
ROI		22%	22%	22%		22%	22%
simple payback		3.7yrs	3.7 yrs	3.7 yr		3.7 yr	3.7 yr
Sell back rate		$0.10	$0.10	$0.12		$0.1	$0.1

However, it is important to promote renewable energy to preserve the environment, control grid emissions, avoid grid losses and create jobs. It is also crucial to consider rooftop solar PV systems for power generation to balance the electricity supply and demand at the lowest to increase the number of customers' buying power. In addition, as many households start generating electricity from rooftop solar PV power, there will be job creation for many people and reduced tariff bills to the households, resulting in improved buying power.

4.5 Cost-Benefit Analysis and Mitigation Options

Subsequently, the cost benefits and mitigation options are summarised in Table 5, reflecting several major stakeholders that will be affected by net metering in Lesotho. The consumers and IPPs under this process will have the cost of the investment, maintenance and operational costs. However, these costs can be avoided through energy sales and reduced costs relating to transportation. Furthermore, the Lesotho Electricity Company's (LEC) loss of revenue can be mitigated through cost-reflective wheeling charges and the efficient use of the transmission network operations and management. Besides reducing the bills, net metering will create more jobs, thus reducing poverty. Households using power will increase significantly, providing a conducive environment, more energy access and grid extension, as well as business generation. Additionally, the government will lose insignificant dividends due to net metering compared to the huge expenses incurred to import electricity from the Electricity Supply Commission (ESCOM) of South Africa and Electricidade de Mozambique (EDM) Mozambique. The net metering system power generation adds power to the electricity grid to alleviate the energy supply deficiency.

Table 5: Stakeholder mitigation strategy

Stakeholder	Costs	Benefits	Net Benefits	Mitigation
Consumer /IPP	Investment, maintenance and operation cost	• Avoided value of energy • Energy sales	• Positive NPV >0, the IRR greater than the discount rate, payback period, PBP< project life • Profitability index, PI >0	Reduced purchasing, shipping, border post and land transport costs
Lesotho Electricity Company (LEC)	Loss of revenue	• Wheeling charges • Less transmission losses	Loss of revenue if the loss in revenue is greater than the wheeling charges and benefits of less transmission losses.	• LEC to charge costreflective wheeling charges • LEC should be more efficient in generating, operating and managing the power system.
Government/regulator	• Greater criticism • Small loss of potential dividends from the LEC	• Less importation of energy (foreign currency saving) • Empowering the majority • More job creation during the construction and maintenance of solar power • Less transmission losses • Less emissions	• Lower LCOE • More energy security with solar systems because they are indigenous	Promote a wider spread increase of renewable energy power systems.
		Fair play on the energy sector, end monopoly by the central utility. Less national energy demand		
Non-solar LEC customers	LEC may increase the tariffs to cover for the aforementioned losses and only non-solar customers feel this	Surety of power supply to meet the demand.		

The stakeholder mitigation strategy shows that net metering benefits both the utility company and the government for positive economic growth. Furthermore, Zahid *et al.*’s study on Pakistan net metering has shown benefits for both the consumer, the power and the utility company due to numerous advantages [78]. The advantages include the export of excess power to the grid, voltage profile improvement, less dependency on the grid, reduction of system losses and credit of extra energy supplied to the grid.

4.6 Avoided Energy Cost

The cost of energy from the grid is \$0.13/kWh, and the net metering cost of energy is \$0.028/kWh. This means that the house can avoid \$0.102/kWh, which will be much lower in Lesotho due to some excluded charges, such as the wheeling charges and the government of Lesotho levies. The avoided energy cost in *Table 6* shows that the energy net electricity charge is very high when the energy consumption is from the utility grid only. However, when solar power is introduced, the net electricity charge decreases. When solar power is doubled, the net electricity charge reduction also becomes significant. The months (February and November) that receive the most reductions and their solar power production show the least net energy charge. This is because the energy demand is lower; hence, the net charge becomes slightly lower than in other months.

Table 6: Monthly energy charge

	Energy Charger		
Month	**Grid only (US \$)**	**With Solar (US \$)**	**With double-sized solar (US \$)**
January	42.65	23.14	3.63
February	38.17	21.07	3.96
March	43.12	24.78	6.43
April	41.47	24.01	6.55
May	42.3	24.56	6.82
June	41.55	24.85	8.16

July	42.68	24.61	6.54
August	43.48	23.7	3.92
September	41.57	22.11	2.65
October	42.7	23.49	4.28
November	41.03	22.3	3.57
December	42.73	23.06	3.4

Furthermore, *Figure 46* shows the lowest avoided energy cost in June, which results in purchases from the utility grid being higher than any month and sales being lower than any month. Again, the avoided energy cost is when solar energy is introduced. However, more avoided cost of energy was observed when solar energy was doubled. In contrast, the NPC and LCOE of the doubled-power solar energy systems are lower than those of the solar power system without doubling the solar energy, indicating the energy cost reduction as more solar power generation is added. This means that there are more savings to the individual household net metering than the community net metering. The system favours the rooftop net metering over the community mini-grid.

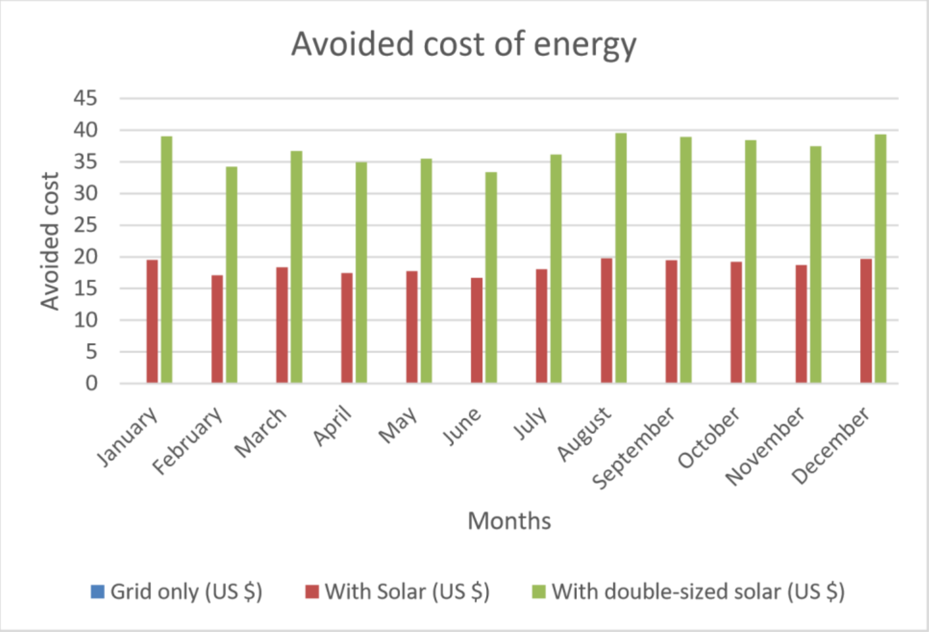


Figure 46: avoided cost of energy.

4.7 Policy Analysis

The feasibility of net metering systems depends on the technical and economic viability of developing policies that can guide the schemes. The scenario of adding solar power systems as shown by Table *4* above increased the present worth of the system to $4,070.00 while the ROI, IRR, LCOE and simple payback are 22.2%, 27%, $0.0.077/kWh and 3.7yr respectively. This scenario provided the net metering systems that are more economically feasible than when the electricity consumer uses from the grid only. Furthermore, doubling the solar power supply increased the system's present worth to $8 128.00, and LCOE decreased to $0.02835/kWh. The system's lower LCOE and high Present Worth with doubled solar power supply become the most economically attractive and viable. The LCOE decreased from the ordinary $0.13/kWh tariff to $0.02835/kWh. However, this lower LCOE excludes the levy charges and other costs like wheeling charges by the utility company.

Therefore, the net metering policy considers the most economically feasible system as the system with a maximum limit of 2kW per household for the MASOWE residential sector. The LCOE of $0.02835/kWh is the minimum possible limit, which would increase slightly when additional levies and some related costs. However, more studies would be needed to discuss the cost-relative tariff under this net metering model. The benefit of having net metering tariff rates less than ordinary grid tariffs is more advantageous to the prosumer than the utility company [79]. This type of scheme causes less friction between the utility company and prosumers due to its suitability to address net metering tariffs closer to the utility grid tariff. Sometimes, this flexibility extends to the possibility of the prosumer not having monetary credit, but requiring electricity bill compensation through excess power production to the grid.

The net metering policy design depends on the types of design, together with the policies and regulations. The country can, therefore, decide to provide a decisive environment for the development of net metering. The net metering policy should consider the three essential strategies for the decision-making to adapt the net metering policy. These three considerations are accounting, restrictions and granularities. These strategies would allow the regulator to define the energy or monetary credit under the net metering system. The policy should provide the direction of the energy credit compensating the prosumer or credit the regulator (utility company). On the contrary, the policy may use money as monetary credit to compensate for the surplus supply of energy from the prosumer. However, to achieve all these requirements, the technical and economic feasibility of net metering should be analysed.

However, the net metering policy defines the rules or guidelines for the technical limit of installation and sets the standards to be followed during the operation [79]. The fact is that unlimited capacity installation can create operation problems for utility investment and the distribution generator. Therefore, to keep the grid safe and stable, restrictive standards must be created. Even if unlimited capacity promotes more incentives to the prosumer and increases the electricity grid's stability and economic growth of the utility company and country, there should be restricted rules and regulations that limit capacity and provide the standard of operation.

It is worth noting that several countries already have net metering. However, the study analyses a few of them to conclude on the technical and economic feasibility of net metering for MASOWE. Due to the low economy of Lesotho, any measures that affect the local private sector would impact the country's economy negatively. Amongst the three strategies mentioned above, energy-limited credit, which provides the net balance resolution between the prosumer and utility company, is the most considered net metering system in this study.

Therefore, it is important to find out how other countries' net metering systems are operating and their possible effects.

However, the granularity of net metering can be spatial and temporal based on the agreement balance of production and consumption to credit both the prosumer and utility company. On the one hand, spatial net metering is when the prosumer is compensated with a small portion of surplus solar energy from net consumption supplied to the utility grid. The spatial energy is also more desirable for installation because it would lower the operational costs between the neighbourhood households. On the other hand, temporal net metering is when the prosumer is credited at the end of the billing cycle or fiscal year [38]. Therefore, the net metering policy should have economic implications to ensure the sustainable implementation of net metering with no significant harm to the local economy and utilities companies.

The low LCOE under Net Metering and high Internal Rate of Return and short-term payback make net metering economically viable. The net metering system for Namibia is meant to add power to the national grid while providing a conducive environment to attract investors into energy generation investment [26]. It also promotes renewable energy and alleviates the quantity of electricity imported into the country. The net metering system also improves investment in small solar energy projects and promotes customer production to export the distribution network while reducing unemployment. The solar energy power production for Namibia should not exit the circuit brake at 500kVA as determined by distribution and approved by the board of directors [26]. The back feeding net metering must have a visibly open, lockable and manual disconnect switch that is accessible and labelled easily.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

In the present study, the technical and economic feasibility analysis for the individuals and 1010 households in the MASOWE net metering system is investigated to provide the potential option to reduce the power demand and provide less costly electricity. The net metering system study analysis performed the HOMER Pro optimisation of the grid-connected solar PV system based on MASOWE household energy load. The HOMER Pro software was used to model MASOWE household consumption against the demand to optimise net present, energy and annual operating costs. The energy demand can be satisfied if the government applies net metering policies that provide alternative options for power generation. The power demand has caused Lesotho to sign contracts with South Africa and Mozambique to export electricity to Lesotho. However, the power shortage and load shedding in South Africa pose a serious power demand threat to Lesotho, which depends on South Africa’s power diversity. Similarly, the Mozambique power purchase agreement risks foreign exchange charges because it is based on the value of the United States dollar to the Lesotho Loti. Thus, Lesotho has to generate its power to survive these threats.

The study assesses the economic feasibility of rooftop net metering for MASOWE households to find the economic viability of a net metering system to address the energy security of supply. The solar PV Hybrid system model was developed for the MASOWE households to supply electricity to the whole house while reducing the bills, creating jobs and protecting the environment. Therefore, the HOMER Pro results select the best optimum results for net metering out of five scenarios. The household’s load profile showed a possible average energy of 10.61 kWh/day, an average power of 0.44 kW, a peak demand of 1.31 kW and a load factor of 34%. These parameters indicate that the selected site is suitable for solar power production. The five scenario cases were for the household (standard solar PV hybrid system, solar PV hybrid system with storage, solar PV hybrid system doubled solar power) and community (traditional solar PV hybrid system and solar PV hybrid system with doubled solar power). The single solar PV hybrid system with double solar power panels seemed favourable. The solar hybrid system selection criteria use the NPC, IRR, ROI, payback time and LCOE [75]. The economic implications of the net metering are concluded based on the Lower NPC, shorter ROI, high IRR, short pay time and lower LCOE.

The study found that the household solar PV hybrid system has a power of 2kW and the lowest NPC of $3,838.88; the operation and maintenance cost of $96.09/yr is the best among all five cases. In addition, the system has the best LCOE of $0.0282/kWh. Therefore, the hybrid system with the lowest LCOE is the most optimum system to be selected for the net metering analysis [55], [74]. The system with the lowest LCOE is the required system that lowers the tariff cost and increases the buying power of the households to increase energy access. The LCOE decreased to $0.0282/kWh also matches the conclusion made by IRENA when they mentioned that the Global LCOE of the PV system has decreased from $0.378/kWh to $0.068/kWh from 2010 to 2019 [49]. The LCOE of $0.0282/kWh is less than $0.13/kWh for Lesotho on the grid LCOE. This reduction of the LCOE implies that the avoided energy cost to the prosumer is $0.102/kWh. This status of decreased LCOE as solar power is doubled, making solar PV power production more attractive for investment [74]. The lower LCOE implies that the project can break even and is profitable. The LCOE is the benchmark to indicate the attractiveness and cost-effectiveness of the system. However, it is crucial to generate adequate solar power to balance the economic implications for the prosumer and the utility company. As a result, the study suggests a policy that limits household solar PV to less than 2 kW because the scenario has demonstrated that the cost will rise, making the system more costly and less appealing.

However, the LCOE recommendation should consider some incentives for utility costs to cater for the wheeling costs [80]. The LCOE of $0.0282/kWh indicates an opportunity for the household to pay electricity at lower bills. However, this value remains small even though the other costs, such as the wheeling charges and levies to the Department of Energy, are not included because they account for a small percentage of the power unit price.

Furthermore, this system’s IRR and ROI were the highest of all the scenario cases at 27% and 23%, respectively. This made the system to be the most economically viable among systems under this analysis for the net metering policy [8]. Therefore, the IRR is the same for the scenarios with different solar power sizes. This reflects the literature above, which has indicated that the IRR remained the same for different system sizes, encouraging more investments in net metering for self-incentivised prosumers [25]. Furthermore, this solar PV hybrid system has a payback period of 3.7 years, making it attractive for investment. This stems from the short payback period, high LCOE and ROI, which are less risky and attractive to investors.

Therefore, high present worth, low LCOE, Low NPC, high IRR and short ROI are the indicators that show that net metering is economically viable for investment and implementation. Moreover, the study concludes that a net metering system for the MASOWE residential sector is economically feasible. Eid *et al.* also have similar conclusions on the analysis of the economic effect of electricity net metering, considering the cost recovery, crosssubsidies and policy objectives [37]. However, this net metering scheme should be costreflective to balance the impact on the prosumer and the utility company.

Furthermore, net metering presents the opportunity for power generation and job creation because of many installations of solar systems and net meters by technicians and energy entrepreneurs. Therefore, the price per unit decreases, attracting more participation from solar power entrepreneurs. This, in turn, results in an increase in the employment rate and the subsequent rise in the community’s buying power. Moreover, net metering attracts more investment in solar PV systems, thus increasing Energy access and security of supply.

The Namibia net metering is important for earning carbon credits on the amount of emissions avoided [26]. Therefore, considering the region in which Namibia is located and its population of 2 million, similar to Lesotho, the system may be adapted and improved to meet Lesotho’s requirements for implementing the net metering system. However, Lesotho remains with the major challenge of localising all energy standards within the SADC. The suitable standard should address both the operation, safety handle and grid integration safe standards to support the grid power supply without stability disturbance in its operation [26]. However, the study recommends the energy credit net metering model for the individual household rooftop solar PV system under well-formulated operation standards due to economic constraints. Furthermore, the energy credit recommended in this study should be without monetary compensation, but only energy credit to the prosumer.

The net metering policies should develop clear operational guidelines and set the minimum performance, safety standards and grid integration standards to save lives and ensure grid stability. Furthermore, these standards could protect the environment by mitigating emissions, including minimum performance standards and using non-polluting equipment for net metering [72]. Moreover, net metering can address the issue of energy accessibility, affordability and reliability to the household to comply with the Lesotho master plan on the country's electricity [4]. Again, this could be the Lesotho energy policy on highlighting net metering as one option to address the energy security of supply strategically.

The economic feasibility of PV net metering for MASOWE residents is economically feasible and has the added advantage of promoting renewable energy, job creation and increasing energy accessibility. It also has the potential to increase and boost the power of supply to the grid. However, in-depth studies are required to assess its impact on the grid’s stability.

Further study is also required to look at how different types of net metering impact grid stability and how that impacts other energy sources and environmental treaties. Real-time data are also required to minimise possible errors that might accrue for the best net metering model and better decision-making for possible net metering policies.

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