National University of Lesotho

Techno-economic analysis and policy design for PV electricity net-metering systems in Lesotho

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A dissertation submitted in partial
fulfillment of the requirements for the
degree of

Master of Science in Sustainable Energy

Offered by the

Energy Research Centre
Faculty of Science & Technology

April 2021

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Abstract

Lesotho imported 65% of its electricity from Electricidade de Moçambique (EDM) and Electricity Supply Commission (ESKOM) in 2019/2020 (Lesotho Electricity Company (LEC), 2020). This is higher as compared to 59% in 2018/2019 (Lesotho Electricity and Water Authority (LEWA), 2019). This shows that there is an increasing demand, but stagnant generation capacity hence the need for the security for the supply of electricity in Lesotho. Studies have shown that the interconnection of Solar Photovoltaic (PV) systems to the grid can reduce electricity imports amongst others. The objective of my study is to design optimum grid-connected solar PV systems for residential, commercial, industrial and institutional purposes; predict the system field performance and do a cost-benefit analysis on net metering.

Optimal PV system is designed using the Typical Meteorological Year data closest to Maseru. PV power and inverter power outputs are calculated for each hour of the given typical year. The different load profiles from the utility are also used. Net metering policy options guidelines are designed such that PV electricity is sold to the grid at the utility retail price with no PV capacity cap for net metered systems. The benefits from net metered PV systems are calculated. These are from surplus sales, avoided energy savings and peak shaving in the billing period of 12 months.

The results show that with the current electricity tariffs, the PV system that gives the net electricity payments of zero at the end of the billing period for commercial and industrial customers results in negative NPV values which indicate that the system is not acceptable. On the contrary, the net-metered residential PV system offers the profitability index of 2.7643 at the discount rate of three percent (3%) which is very attractive for investment on the customer’s perspective. The internal rate of return of the project is thirteen percent (13%). Based on these results, it is concluded that with the current tariff settings for residential customers, only the residential PV net metering is technically and economically viable. As for the commercial and industrial activities, PV net metering is technologically viable but not economically viable.

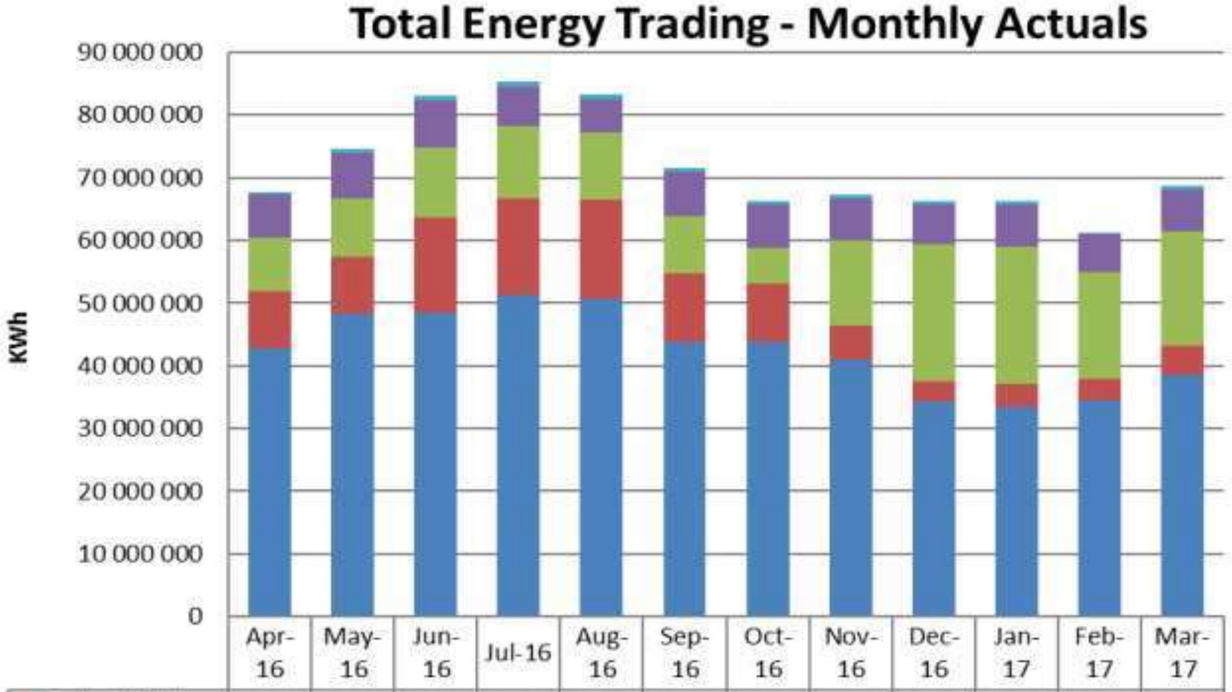
The changes in some variables such as dropping of solar PV systems’ capital and the increase in energy charges to $0.0423 and $0.039 for commercial and industrial customers respectively, can make the systems acceptable. The reasonable Net Present Value (NPV) values are likely to increase the adoption rate of electricity net metering. However, to attract more investment into the net-metering system, the interest rate of the investment should always be greater than the inflation rate. The larger

the range between the two, the more attractive the investment can be.

Chapter 1: Introduction

1.1 Electricity Situation in Lesotho

Literature shows that electrical energy is central to the economy of any country in the world [1]. Lesotho is not an exception because electricity is considered the main driver of Lesotho's socio-economic development. On the contrary, the supply is lower than the demand (MoE, 2015) [2]. The demand keeps on growing. The peak demand increased from 140 MW to 166 MW (2018) of which 72 MW (43%) is locally generated and the rest of 57% is imported from Electricity Supply Commission (ESKOM) in South Africa and Electricidade de Moçambique (DEM) in Mozambique [3]. This situation imposes a *lack of security of supply* for the country. Figure 1 shows that peak demand is obtained in July. It can also be seen from the figure that generation capacity through 'Muela was lower than the demand for 2016.



	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17
Qacha (KWh)	501 03	686 31	771 20	773 29	751 75	691 96	670 19	670 19	604 38	637 06	1 506	561 75
Clarens (KWh)	6 716	7 186	7 444	6 226	5 232	6 935	6 849	6 624	6 181	6 596	6 073	6 595
Msu Bulk (KWh)	8 647	9 360	11 135	11 587	10 851	9 268	5 721	13 666	22 015	21 897	17 015	18 264
EDM (KWh)	9 055	9 021	15 225	15 500	15 680	10 965	9 255	5 410	3 230	3 720	3 360	4 805
Muela (KWh)	42 803	48 344	48 484	51 239	50 763	43 717	43 883	40 970	34 252	33 453	34 574	38 444

Figure 1: The bulk purchases for energy from ESKOM (Qacha, Clarens and Maseru), EDM and 'Muela (2016)

At the end of 2014, Lesotho had achieved 34% electrification and currently is more than 42% in response to SE4ALL [2]. However, the electricity charges keep on increasing. The local utility (Lesotho Electricity Company or LEC) proposed that as of 1 May 2020, an increment of 32% be added to the electricity charges. The proposed charge per kWh increased from M1.47 ($0.099) to M1.94 ($0.130) for the domestic customers [4]. The national electricity master plan for Lesotho addresses the distributed generation including solar energy-based systems in section 7.1 which form the basis of this study [5].

The master plan further states that about an average of 3.7 to 7.0 kWh per square meter of solar irradiation is received in Lesotho, which makes solar one of the best options for increasing generation capacity for the country. According to the Department of Energy Lesotho (2017), the estimated technical potential for the solar resource is 118MW of generation capacity [6]. This is indicative that for electrical generation systems, solar photovoltaic (PV) is a form of renewable energy that can be used to ensure the reliability of supply. The subsection below provides an in-depth look into solar PV.

1.2 Current initiatives to solve electricity problems in Lesotho

As an initiative to solve the problem of lack of security of supply, the government of Lesotho through the ministry of Energy and Meteorology (MEM) developed a policy framework that lessened constraints for Independent Power Producers (IPPs) participation in power generation [2]. One of the strategies opted in the policy is to introduce the Net metering system to encourage the implementation of renewable energy technologies [2]. This policy has not been implemented since 2015.

However, the implementation of net metering requires a policy that addresses issues of prosumer compensation rates, recovery of utility's transmission, distribution costs, and other fixed costs, distributed generation codes of standards, and capacity limits [7][8][9]. The policy should have also taken into consideration the transferred cost from net metering customers to non-net metering customers. Currently, none of these issues have been addressed in the current Lesotho energy policy. There is no legislative measure for the implementation of net metering schemes. Hence, it has not been implemented as yet.

1.3 The background for Solar PV systems and net metering

A grid-connected solar PV system comprises of PV array which is the electricity generator, the inverter to convert direct current (DC) to alternating current (AC), and the voltage transformer [10]. Solar meters including net meters are used to measure electrical consumption and the amount of electricity injected into the grid. The different authors differently define the net metering system [7][11][12]. However, Pace and Gattie (2017) define it as the matching of energy provided to and obtained from the grid by a solar rooftop vendor [13]. Roux and Shanker (2018) define Net metering as a contractual obligation between the energy distributor and self-generating customer [11]. The definition given by Cox et al (2015) makes the concept even clearer. They refer to it as a policy that is based on tariff; the policy that determines how much is in monetary value, the excess electricity that is given to the utility by the prosumer. That electricity is generated on-site from the renewable energy system such as Solar PV [9]. There are several policies designed to enable the penetration of the solar PV into the energy mix. Net metering is regarded as one such enabling policy for solar PV systems as indicated in figure 2. This study concentrates on the use of net metering on the grid interconnected PV systems for the Lesotho context with focus on their technological and economical viability, and suitable policy design.

Net metering was initiated in 1983 in Minnesota, United States. Policies regarding net metering took off from the year 2000. The system has been adopted by many countries since then. The global status report by REN21 for 2018 shows 23 high-income countries, 17 upper middle income, 21 lower middle income and 2 low-income countries that have adopted the Net metering system into their energy policies. Among these countries, 14% is made up of nine (9) African countries. These are: Gabon, Mauritius (UMIC), Egypt, Ghana, Kenya, Lesotho, Morocco (LMIC), Senegal, and Tanzania (LIC). In Africa, Net metering is operational in South Africa and Zimbabwe (where prosumers get incentives) and Lesotho at Moshoeshoe I International Airport (where there is no incentive for prosumers). Kenya, Ghana, and Cabo (Cape) Verde have an existing regulatory framework but net metering is not yet applicable [11]. Congressional Research Service (CRS) report (2019) indicates that by the end of April 2019, 45 states in the United States had net metering policies in place and ready to serve customers [8].

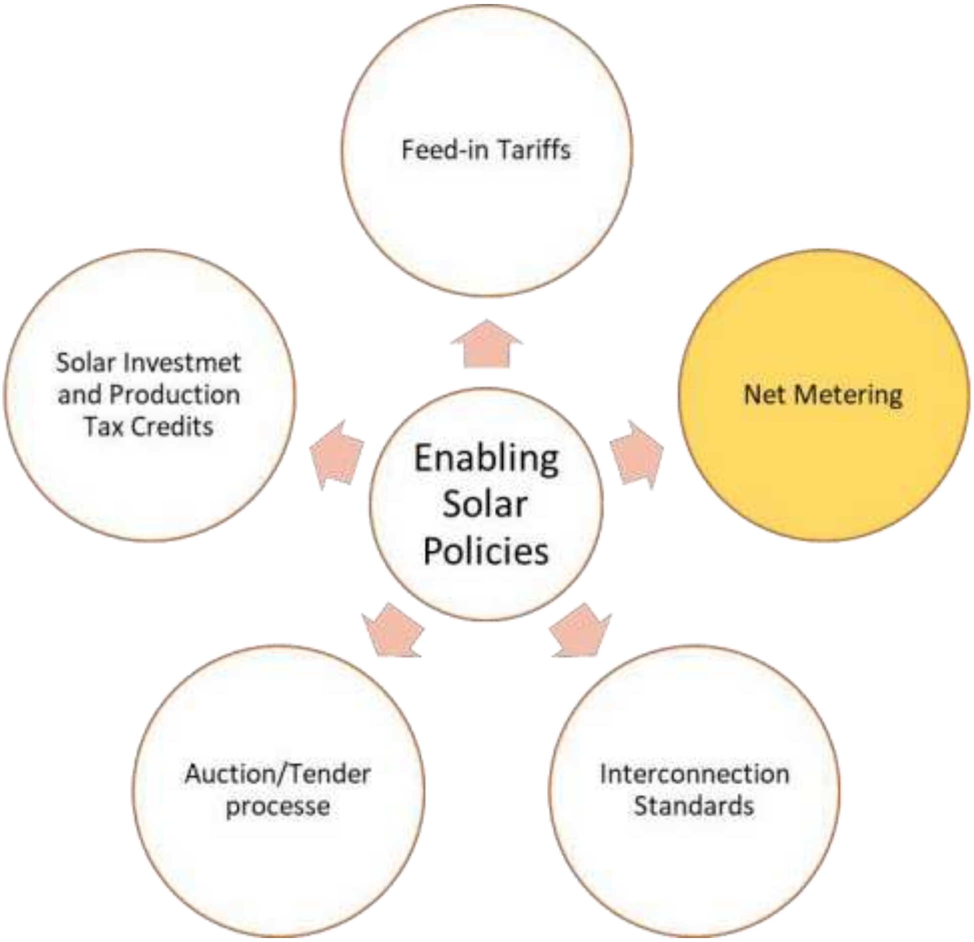


Figure 2: Solar PV enabling Policies (Source: Own elaboration, Solar power: policy overview and good practices)

In the net metering system, the bidirectional meter is used to measure the total energy flow from either direction. In some cases two meters are used; one measures energy consumption from the grid while the other measures the PV energy injected into the grid. The bidirectional meter works in such a way that when the electricity customer uses electricity from the grid the meter runs forward. But if the customer is consuming the same amount of electricity generated, the meter stops recording. If there is surplus electricity generated and it is injected into the grid, then the meter runs backwards [14]. Energy charges for grid energy per unit and the energy compensation charges for energy injected into the grid are discussed in Chapters 2 and 3. Figure 2 shows the schematic diagram of net metering system.

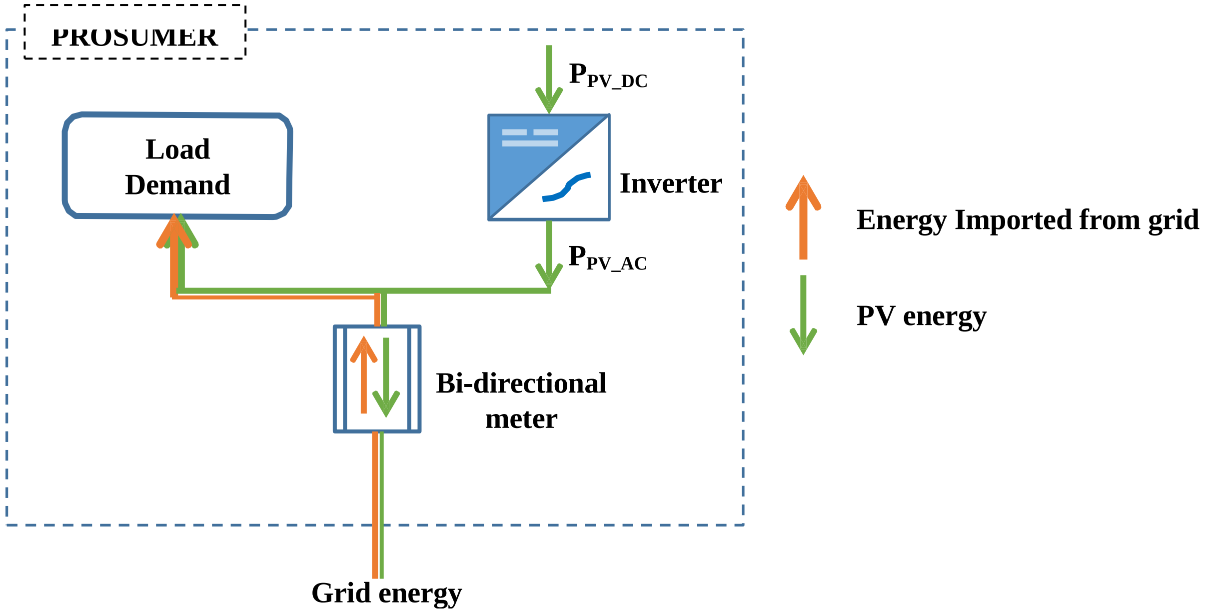


Figure 3: How net metering works

The performance prediction of PV systems and their economic analysis has been performed by several authors using different approaches. A simple spread-sheet-based mathematical model for the system sizing has been used by some [15]. For this study, the same approach is used, and the methodology is discussed in chapter 3.

1.4 The Current status of electricity net metering policy for Lesotho

Policy statement number six (6), addresses power generation that ensures the security of electricity supply in the country. One of the objectives stated is to enhance private sector and cooperate associations' participation in the supply of electricity. The policy has strategically proposed the introduction of Net metering system to encourage broader acceptance of renewable technologies. Its incorporation has a high potential to boost distributed generations of solar PV systems.

According to policy statement seven (7) regarding power transmissions, a second objective is about promoting non-discriminatory access to the grid prescribed wheeling charge, however, the fourth strategy only guarantees grid access to IPPs producing at least 500 kW. This capacity cap is likely to be changed depending on the desired adoption rate that can be set.

Statement fifteen (15) is about energy pricing that will ensure cost recovery. The second objective targets to promote private investment in the sector. Net metering is suitably one of the best strategies that could be used to achieve the objective.

1.5 Problem statement

More households and businesses are connected to the grid every year while the national generation capacity remains at the same. As a result, more load shedding is expected and so are the increased electricity imports from ESKOM and EDM. Electricity prices keep on increasing too. Renewable energy technologies are looming as decentralized and distributed generation of electrical energy across the world. The previous studies mentioned in previous sections have proven that in most countries outside Africa, the grid-connected net-metered PV systems are the ultimate solution to accelerated access to electricity that is affordable, reliable, and sustainable. They are also suitable to balance the electricity demand and supply of a country [16][17][18].

Therefore, the hypothesis drawn for Lesotho based on literature is; w*ith a suitable policy design, a net metering scheme for electricity is technologically and economically viable for residential, industrial, and commercial purposes in Lesotho*. The purpose of this study is to prove or conflict with the hypothesis.

The study outcomes will also provide the basis for an optimal solution to reduce among others, electricity import for Lesotho.

1.6 Formulation of study objectives

The main objective of this study is formulated from the study questions for optimal PV system design and net metering policy. The main research questions are;

- Is the net metering technologically and economically viable for residential, industrial, and commercial purposes in Lesotho?
- Which net metering policy design is best for the Lesotho context?

In trying to answer this question, the study looks into on-grid technological viability in terms of system design for electricity generation, the economic viability of the proposed system in terms of cost-benefit analysis and, policy design for electricity net-metering systems to regulate compensation rates without compromising utility costs in Lesotho.

Therefore, the four objectives stemming from the research question are;

- To design and analyze the proposed optimum PV system performance under the net metering scheme for residential, industrial, and commercial purposes.
- To perform cost-benefit analysis on net metering
- To design net metering policy guidelines with policy options for prosumer compensation rates for the

Lesotho context

Eventually, the study will detect whether net metering provides positive value for Net-Present Value at the end of the project life or not. The minimum prosumer compensation rates and the Levelized cost of electricity (LCOE) generated from the proposed PV system under the utility customer types, namely; residential, industrial, and commercial will be determined.

1.7 The benefits of the study

Net metering is a new technology that is used effectively by a few African countries such as South Africa and Zimbabwe and used by many countries on other continents. It has shown variable techno-economic impacts in those countries to the customers and distribution companies some of which are not good [11].

For its successful use in Lesotho, its techno-economic impacts must be fully investigated and understood. The outcome of the implementation of this research recommendations will reduce the load shedding problem, flatten the national power demand load profile, reduce electricity imports, bring other opportunities on business growth and reduce poverty, reduce unemployment rates and promote women empowerment through access to electricity. More importantly, it will reduce the negative impact on the climate through the use of clean energy in Lesotho.

The findings will re-inform new decisions on energy policy design. The policy options for net metering compensation rates will be used as the basis for new rates for net metering customers. Consequently, many benefits for various categories of beneficiaries are possible. The list of beneficiaries from this study is categorized into net metering customers, utility and regulatory institutions, commercial institutions and government institutions such as health facilities and national security. This study on Net Metering can be used as a tool for demand side management and development of sustainable community/society to fasten economic growth from micro to macro level hence ability to alleviate poverty.

Similar studies have been carried out in many countries outside Africa according to the literature. The lessons learned from the experiences of such countries will be turned into an opportunity for Lesotho.

The outline of the study follows the sequence of introduction in section 1, Literature review in section 2, Methodology is discussed in section 3, Results and interpretation follows in section 4, the conclusion and recommendations are in section 5.

Chapter 2: Literature Review

2.1 The advocacy for Solar PV systems

The renewable energy sources that are capable of being net-metered are wind, hydro, bioenergy and solar PV generated energy. The choice of solar PV amongst other renewable resources is explained by REN21 (2019). The major advantages of the PV system over others are; it can be sized according to the consumers' needs and it has a lifetime of 25 years on average, with low maintenance requirements [19]. The trends of PV indicate the tremendous growth from 2014 to 2019 due to the decreasing capital costs of PV systems as shown in **Figure 1** [20][21]. This was also predicted by Benatiallah et al (2017) that PV is more likely to meet most of the energy demand worldwide [10].

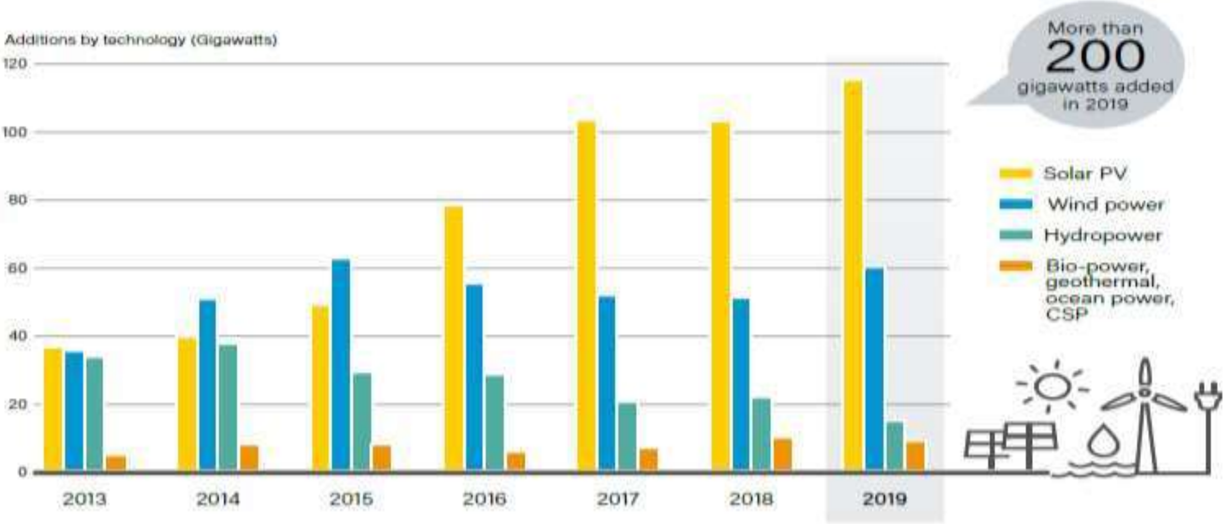


Figure 4: The growing installed capacity of PV as compared to others from 2013 to 2019.

The opportunities for solar DG can be expressed not only in monetary terms but in terms of social and environmental benefits. Solar DG of Solar PV has price mitigation benefits which have a reducing effect for electricity demand hence reduction of prices in electricity markets, which is a benefit for the consumers while the utility can generate savings from transmission and distribution losses [22]. Since the DGs are located in the area of consumption, the effects of distribution and transmission botches or losses are not greatly felt [22][23]. Therefore this offers grid security and savings in transmission and distribution losses. Furthermore, localized generation from DGs does not need new transmission infrastructure, consequently creates jobs for the local people that have a positive impact on tax revenues [22][24].

Since the DGs resources are not fossils related, emissions are reduced which gives environmental benefit [22][23]. They also avoid capacity reserve costs associated with generation capacity by decreasing peak demands. The decreasing peak demand resulting from DGs is capable to lower the utility capacity requirements and prevent load shedding and transmission line overcrowding [22][23]. The rooftops solar PV has the ease of implementation in terms of site selection and permits, the underutilized rooftops are used for PV generation saving the land for other productive land uses [24].

2.2 Designing optimum solar PV system

Designing the optimum solar PV systems requires meteorological information about the place of system location. The information includes irradiation on the horizontal surface, diffuse radiation, wind speed and the ambient temperature of the place. These are necessary to calculate the major system parameters such as solar angles and the hourly sun positions in the sky throughout the year. Eventually, the PV system performance can be predicted.

2.2.1 Solar angles and sun position

One type of solar angles is those that describe the position of the sun in the sky; declination angle (δ), hour angle (ω), solar altitude angle (α), solar zenith angle (φ), and solar azimuth angle (θz). The second type is the surface sun angles; tilt angle (β), surface azimuth angle (Zs), and the angle of incidence (θ). Abood (2015) explains these angles in detail [25]. In the southern hemisphere, the optimum azimuth is 180 degrees for the flat plate collectors, while it is 0 degrees in the northern hemisphere. The cosines of θ and θz give the geometric factor known as R_b. The R_b is defined as the ratio of beam radiation on the tilted solar module to that on the leveled ground at any time [26]. The collector performance is reliant on tilted angle towards the sun [27]. The most studied solar resources are beam radiation, diffuse radiation, and ambient temperature [28][29]. These vary depending on the time and location of the place been studied [29][30]. Due to these restrictions, the designer of the PV systems has to ensure the system captures as much irradiation as possible [30] [31]. This is to say, it is possible to do the simulation of daily, hourly, and monthly average radiation on horizontal and tilted surfaces, which follows in the subsequent chapters for the Lesotho context.

2.2.2 The performance prediction of PV systems

The solar PV system's performance can be predicted and the factors which influence the performance are discussed by Vidyanandan (2017), of which only three are discussed for this study [32]. These three are variations in solar irradiation, module temperature and the tilt angle of the module. The SMA (2020) gives an account of factors influencing performance ratio some of which are discussed in this paper [33].

2.2.2.1 Performance Ratio, P_R of the PV system

The performance ratio of the PV plant may be defined as the percentage of energy available after deducting all the energy losses. It is given as the ratio of the final energy yield of the PV system to the reference yield. It is used to provide information about the overall losses incurred by the inverter in converting DC to AC power. The list of losses includes the optical losses (Shadings, IAM, soiling), the array losses (PV conversion, aging, module quality, mismatch, wiring, etc) and the system losses (inverter efficiency in grid-connected, or storage/battery/unused losses in stand-alone, etc). The PR is an important metric in the PV industry and it is often used as a contractual condition/warranty when commissioning a PV system or for the verification of the annual yield.

2.2.2.2 The electrical losses

The losses incurred are the array capture losses from the PV and system losses from the inverter, transformer, and AC wiring losses [34]. The technical losses can be classified as system losses and collection losses.

2.2.2.3 Collection losses

The difference between the reference yield and the array yield is referred to as the collection losses (L_C). These losses can reduce the PV output at the location of the plant. This impacts the number of PV modules to be used to give the desired power output. Simply put, the number of PV modules used is dependent on the technical losses incurred and the geographical location. The collection loss includes array losses, DC wiring losses, module quality losses, shading losses, and dirt.

2.2.2.4 System losses

The difference between the array yield and the final yield represents the system losses (L_S). The system losses represent the inverter losses, transformer losses and AC wiring losses. Differently installed PV systems with different inverters, transformers and AC wiring will have different system losses.

2.3 An overview of the net metering policies

Designing the policy for net metering of grid and PV energy has requirements that need to be fulfilled for it to be implementable. Some of the requirements are the technical standards and capacity limits for the grid-interconnected PV systems. According to Anjali and Pankaj (2014), Germany, Japan, and California implemented similar measures or policies when facilitating the development of rooftop solar PV. Some of these measures are sustainable business models and metering arrangements. Japan and California used net metering for different purposes as indicated in **Table 1**. Japan used it to control higher consumer tariffs and promote captive consumption while California used it to enable the development of distributed generations of PV systems [24].

Table 1: Reasons for implementing net metering policy according to country

Country	**Reasons for implementing net metering policy**
Cyprus	option for curbing electricity bills
Japan	Control of consumer tariffs
California	Promote PV systems
South Africa	Increase Renewable energy mix and increase generation capacity
Cabo Verde	To increase Renewable energy mix and reduce dependency on imports
Philippines	To increase Renewable energy mix and reduce dependency on imports
India	To boost solar rooftop development

Source: Garg and Sinha ( ) Roux and Shanker (2018)

Anjali and Pankaj (2014) acknowledge the need for a policy and regulatory framework that can boost market progress for rooftop solar PV [24]. They encourage the use of implementation models and roadmaps to initiate market growth. For that to happen, the regulatory institutions need to clearly define technical standards that will guide installations matching the rooftop solar PV life and sustainable grid interconnections [24].

2.3.1 Arguments on net metering

Although the net metering system seems to be applauded by many countries, there are still some setbacks argued in literature. Subsidization is one problem in which net metering customers avoid paying for transmission and distribution fees [35]. In this case, there is a potential cost shift (cross-subsidy) transfer from net metering customers to those customers not participating in net metering. This issue needs to be addressed in the policy design. For this study, it is discussed in chapter 4.

2.4 Economics of grid-connected and net-metered solar PV

2.4.1 Sensitive economic parameters

According to Abdulkarim (2018), the economics of solar PV is highly influenced by six factors including system lifetime period, which is an average of 25 years, and the solar module efficiency that keeps on increasing every year [36]. The PV system cost is composed of capital cost, replacement cost, operation and maintenance cost and cost of energy which needs to be taken care of during the economic analysis of solar PV system in monetary terms. Other non-monetary variables that cannot be ignored are a renewable fraction, a simple payback period, and a discounted payback period. These variables have been used by Hemapala and Jayasinghe (2017) in techno-analysis of net-metered solar PV for a commercial building [16][37]. They are also used in this study inclusive of residential and industrial purposes. Mejdalani et al (2018) explain more about the major variables on which net metering depends and categorize them into four groups. Such variables are shown in Figure 5 [7].

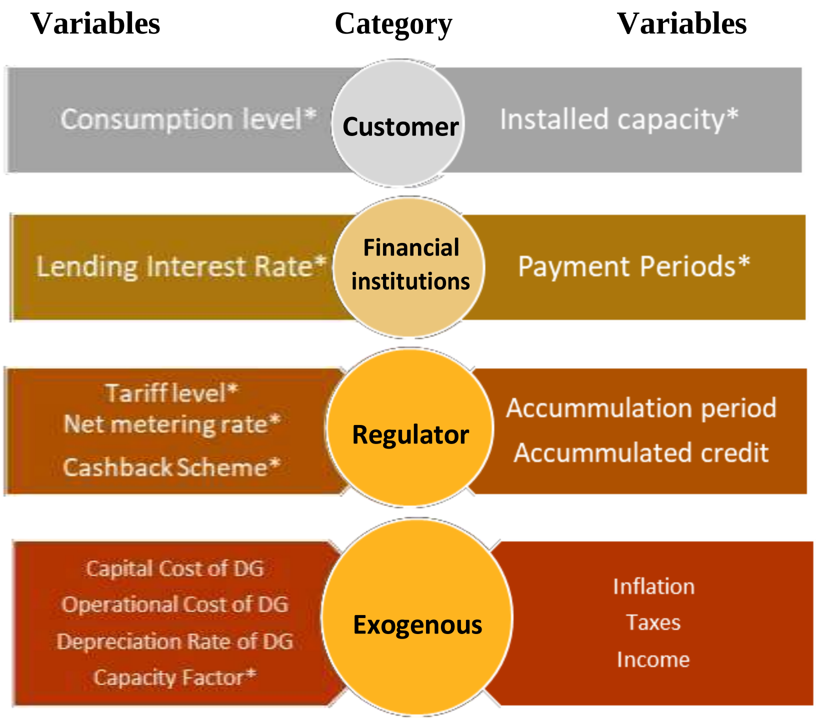


Figure 5: Sensitive economic variables for net metering, Adapted from Mejdalani et al (2018)

*Variables whose sensitivity was simulated

Overall, 7 out of 8, tested variables gave a positive effect on the DG adoption rate. The lending interest rate was the only tested variable which tested negative. Its increase has a negative impact on the adoption rate of DG [7]. The report conducted by Beach and McGuire (2013) for Arizona Public Service indicated that the costs in both residential and commercial markets are lower than the benefits with a benefits/costs ratio (also called profitability index) of 1.54. For this instance, the benefits are more than costs by 50 percent [22].

The economic indicators such as net present cost (NPC) and the cost of unit energy (LCOE) are the determinant of the profitability of a system. Mansur et al (2020) used the NPC and LCOE in their study for a technical and economic feasibility analysis for St. Martin‟s Island [17]. The associated equations are shown as equations 1 and 2 for the calculations of these indicators;

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} \qquad \text{Equation (1)}$$

$\boldsymbol{C_n} = \mathit{Net\ cash\ flow\ at\ time}$, $\boldsymbol{i}$ = *Internal rate of return,* **n**=*time of cash flow,* **N**= *total number of periods*

$$LCOE = \frac{I + \sum_{t=1}^{n} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad \text{Equation (2)}$$

$\boldsymbol{C_t} = (O\ \&\ M)\ \mathit{expenditures\ in\ year\ t}, \boldsymbol{E_t} = \mathit{the\ energy\ yield\ in\ year\ t}\ , \boldsymbol{I} = \mathit{the\ initial\ investment},$

$\boldsymbol{n} = \mathit{the\ investment\ period}$

Bhattacharyya (2011) classifies the payback period and the average rate of return on investment as indicators of cost and benefit under methods without time value. The payback period specifies the time needed for the amortization of primary investments seen during the generation of cash flow within the project [38]. The shorter payback period indicates quicker payment for borrowed funds. This indicator does not take the flow of cash over project life into consideration. On the contrary, on an investment, the average rate of return is defined as the ratio of an annual profit made over an initial investment. The focus of this indicator is on the cost-effectiveness of the system [38].

Using the method that engages time value, NPV, and internal rate of return (IRR) are useful indicators. Equation 3 shows a different way of calculating NPV.

$$NPV = \sum_{t=1}^{N} \frac{R_t - C_t}{(1+i)^t} - I_0 \qquad \text{Equation (3)}$$

$\boldsymbol{R_t} = Revenue\ in\ year\ t, \boldsymbol{C_t} = cost\ in\ year\ t\ , \boldsymbol{i} = discount\ rate\ , \boldsymbol{I_0} = initial\ investment.$

If the PV system shows a positive value for NPV, that is an indication that it is acceptable and the highest NPV value shows the better choice. The discount rate that can make the NPV value to be zero is called the IRR. Then equation 3 is modified to equation 4. The choice of the PV system with a discount rate less than IRR is economically acceptable.

Romeo (2018) warns that the PV systems of different sizes can have the same IRR and if that is the case, the participants of net metering are likely to install larger systems if not regulated [39].

$$IRR = \sum_{t=1}^{N} \frac{R_t - C_t}{(1+i)^t} = I_0 \qquad \text{Equation (4)}$$

The mentioned parameters will also be used for this study for techno-analysis of net-metered PV systems for residential, industrial and commercial in the context of Lesotho.

2.4.2 The current tariff system for Lesotho

Currently, Lesotho uses two types of tariffs, increasing block tariff, where the first 30 kWh/month are subsidized with the assumption that the poor household will benefit to cover the electricity basic need such as lighting and charging the cell phones [40].

Table 2: Approved Energy Charges for 2020/21 by LEWA Board [42]

Customer category	Current Energy Charge (M/kWh)	Approved Energy Charges (M/kWh)	Adding Customer Levy @M0.043/kWh	Adding Rural Electrification Levy @M0.02/kWh large customers and @M0.035/kWh for others	Final Approved Energy Charge	Current energy charges including levies
Industrial HV	0.1936	0.1936	0.2359	0.2559	0.2559	0.2559
Industrial LV	0.2144	0.2144	0.2567	0.2767	0.2767	0.2767
Commercial HV	0.1936	0.1936	0.2359	0.2559	0.2559	0.2559
Commercial LV	0.2144	0.2144	0.2567	0.2767	0.2767	0.2767
General Purpose	1.5835	1.5835	1.6258	1.6608	1.6608	1.6608
Domestic	1.4009	1.4009	1.4432	1.4782	1.4782	1.4782
Street lighting	0.7952	0.7952	0.8375	0.8725	0.8725	0.8725
Lifeline Domestic	0.6500	0.6500	0.6923	0.7273	0.7273	00.7273

According to LEWA (2020), LEC uses a mega-flex Tariff which is found to be more costly than the proposed Nightsave Urban Large Tariff which currently has some problems [41]. Mahony and Baartman (2018) indicate that mega-flex Tariffs differ according to the seasons and per time-of-use duration amongst others [42]. From **Table 1**, the tariff components for residential customers are shown in equation 5 while for high voltage customers (industrial and commercial) is shown in equation 6.

Tariff1 = Energy Charge (M/kWh) + Customer Levy (M/kWh) + Rural Electrification Levy (M/kWh)

Equation 5

Tariff2 = Energy Charge (M/kWh) + Demand Charge + Customer Levy (M/kWh) + Rural Electrification Levy (M/kWh)

Equation 6

Where industrial and commercial customers are charged rural electrification levy of **$0.00132/kWh** (**M0.02/kWh)** and **$0.00231/kWh (M.035/kWh)** applies to the general purposes, domestic, street lighting, and lifeline domestic customers. The tariff1 is **$0.09762/kWh** (**M1.4789/kWh)** and Tariff2 is

$0.01694/kWh (M0.2566/kWh) plus the demand charge of **$18.01/kVA (M272.796/kVA)** for high voltage class**.**

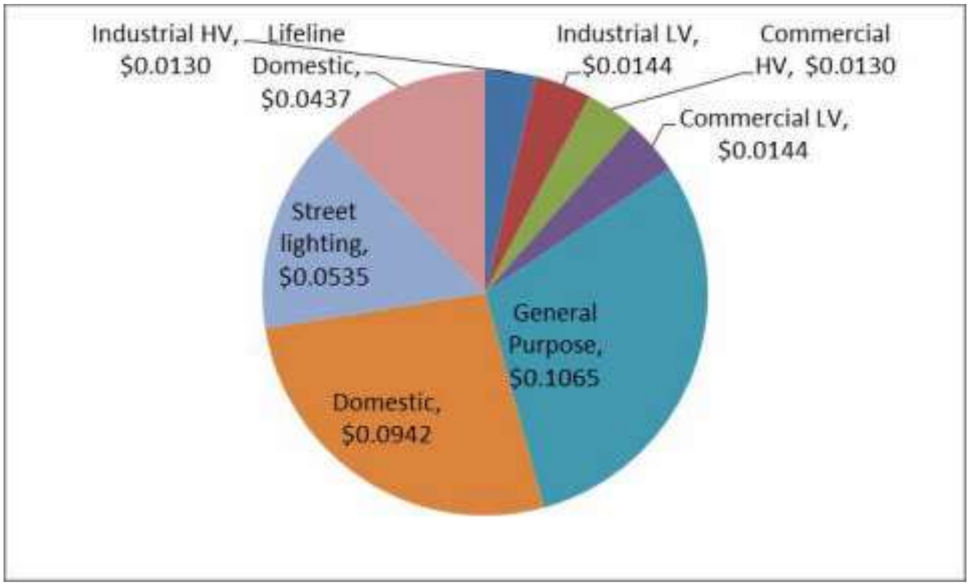


Figure 6: The converted energy charges for different customers

The energy charge can further be unbundled into the cost of producing electricity and value-added taxes.

Table 3: Electricity retail price breakdown per kWh for Lesotho

Allocated charges	**M/kWh**	**%**
Energy Charge	0.2144 to 0.6500	29.5 to 89.4
Customer Levy	0.0430	5.9 to 15.5
Rural Electrification Levy		
- Large customers	0.0200	7.2 to 7.8
- Other customers	0.0350	2.1 to 4.8
Total charges	0.7273 to 1.6608	

Presently, LEC charges regular customers based on the grid imported electricity which may not be the case with prospective NEM customers because they will be generating their own power. The utility on the other hand bears the costs of electricity procurement, operation and maintenance of the transmission and distribution lines, as well as the transformers. As a result, some of these costs are transferred to the customers. LEC's revenues rely purely on the sale of electricity and government subsidies.

2.5 Net metering Policy structure

Three major factors are considered when designing an energy policy as depicted by Kumar (2012). One of the factors that are appropriate for this study is the techno-economic concerns which will be used to measure the limitations involved in installing the solar PV technology in consideration of available economic choices [18]. Mejdalani et al (2018) add that net metering in particular, involves the decisions made by the utility, the customer and the regulator as stakeholders, and there should be regulations to assist to build trust amongst them [7][43]. The availability of solar insulation that differs from one place to another and the land availability for a solar farm are the influencing factors for the variability of the solar power generation policies and regulations [43]. Figure 5 shows the organization of decision concerns and policy controls.

For the regulatory concern of accounting, the monetary credits have to be stated whether they are at the premium rate, wholesale generation rate or retail rate. As for the net balance resolution, if the self-generation and consumption are balanced, then the temporal terms are chosen. In terms of balancing aggregated distributed generators, the spatial terms are considered.

The results obtained by Jia et al (2020) indicated that factors such as the electricity demand have an impact on the effectiveness of the net metering policy [44]. The policy becomes effective when the electricity demand is higher and the area involved has higher solar irradiation. Contrary to this, the net metering policy becomes ineffective. The high electricity demand result in better unit revenue for the prosumers, hence more investment in PV systems can be encouraged. Jia et al (2020) further point out that a well-designed net metering policy should be able to cover the costs of PV power generation systems. If subsidies are offered, they should range between 0.05 and 0.27 yuan/kWh and the policy will still be effective.

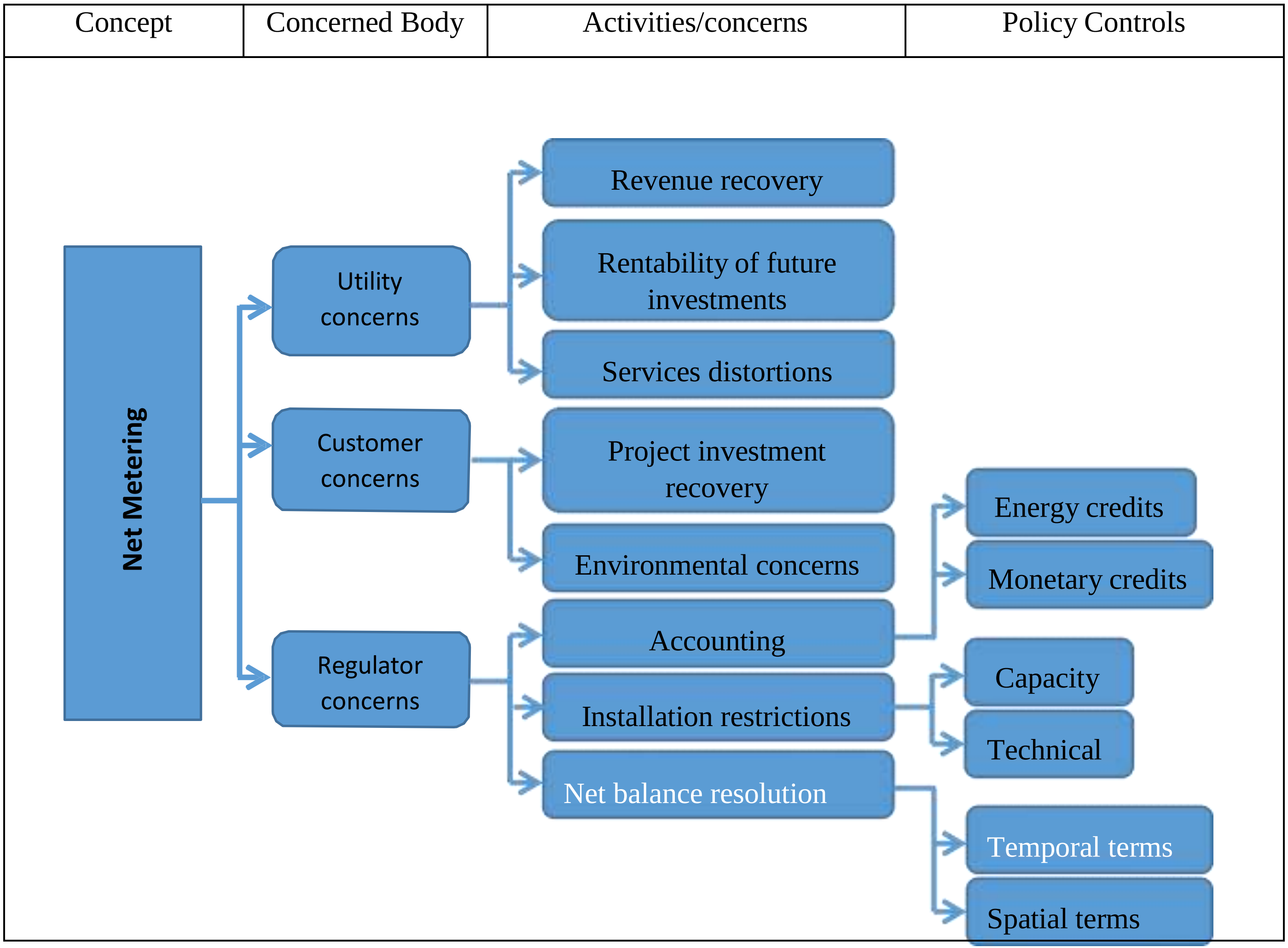


Figure 7 : The net metering decision concerns by stakeholders. Source: Own elaboration

2.5.1 The cost components for Net metering customers

Table 4: Table showing the cost components for electricity for two categories of utility customers

Net metering Customers [22]	**Non-Net metering customers**
TSO's fees	Value Added Tax (VAT)[42]
Ancillary services	Demand charges[18]
Long-term reserve capacity	system infrastructure charge
High voltage networks	distribution charge[18]
Medium voltage networks	Government levy[42]
Low voltage networks	

Public Service Obligations (PSO) levy	-
Renewable Energy Sources (RES) fund	-
Capacity reserve	Capacity reserve

Table 1 shows that there are varieties of charges which are considered by the utility when setting the electricity tariffs for customers. In this case, the net metering customer charges are compared with the non-net metering customer charges. The charges may differ from one country to another. Other charges may be added or removed.

The demand charges apply to industrial and commercial customers. They are charged during the customer's peak use of electricity [14]. With the use of net metering, this charge can be avoided because the PV power generated at peak sun times from the PV system has the ability to shave the peak during the customer's peak usage. For the fact that the residential net metering customer's demand is likely to be the same as the typical customer when they start taking electricity from the grid, especially at sunset, some utilities have introduced the demand charges for the net metering customers [14].

2.6 Case studies

2.6.1 Comparison of high income and low-income countries

Case 1: Cyprus

Cyprus is a high-income country under the World Bank classification. Nikolaidis and Charalambous (2017) looked at both the customer and the utility perspectives and discussed the key finding aligning the concealed policy and financial implementations. In Cyprus, the NEM customers are charged according to their installed PV systems rated capacity. The use of system charges is shown in the table below.

The prosumers are paid for reducing the transmission losses in the grid. The power losses credit paid to prosumers by the utility for its avoided costs is calculated by:

Power losses credit = (Loss Factor) *(cost of losses)* (PV Energy yield)

Equation 7

The loss factor varies between the low voltage levels to high voltage levels.

Cyprus clearly states the use of the system's charges that need to be paid to the utility by the customer.

Table 5: Approved UoS charges currently applying in Cyprus

Use of system	**Per kWh charge (€/kWh)**	**Description**
Cyprus TSO	0.0009	Operating costs of the Transmission System Operator of Cyprus
Ancillary services	0.0024	Frequency (i.e. primary, secondary and tertiary reserves) and voltage support (i.e. reactive power management) services provided by EAC
Long-term capacity reserve	0.0053	Costs of providing an adequate reserve margin of installed generating capacity
HV System	0.0099	Network costs for the high voltage system
MV system	0.0153	Network costs for the medium voltage
system LV system	0.0169	Network costs for the low voltage system

Case 2: United States

The United States is classified under the high-income countries by The World Bank. Schelly et al (2017) indicate that utility companies are bound by the Energy Policy Act to connect prosumers on the grid. However, there are common inconsistencies in net metering policies across the United States; the compensations are not so clearly defined. This can act as a barrier to its adoption and lead to prosumers installing battery banks and leaving the utility. More of such systems may lead to the utility death spiral.

Case 3: South Africa

South Africa is the immediate adjacent country with Lesotho. Lesotho is entirely land-locked in South Africa. Consequently, both of these countries are categorized as medium-income countries by the World Bank. Electricity net metering started as a pilot project on two municipalities in eThekwini in the Kwazulu Natal Province and Nelson Mandela Bay located in the Eastern Cape Province. The former compensates at 65% of the retail price while the latter compensates at import tariff which is the maximum (from 0.06 to 0.12 USD/kWh) as shown in Table 6 [11].

It is not stated how the compensation rate has been achieved and what it entails. But with the compensation of 65% of the retail price, for this paper, it is assumed that 35% covers the fixed costs and service costs. On the other hand, compensating at import tariff burdens some costs to the non-net metering customer and this is highly discouraged in the literature.

Case 4: Ghana

Ghana is an African country located in central Africa. In this country, the utility credit every kWh of electricity injected into the grid for a credit of 1 kWh by the end of the billing period to offset the prosumer's consumption of the utility's power. The excess energy credits are carried over to the next billing cycle until the calendar year ends when they expire. The prosumer pays the levies, taxes and other charges to the utility. The grid injected electricity price is the end-user tariff charged [11].

The major interest for the prosumer in this country is to lower the costs of using electricity from the utility. The profits are not expected from self-generation systems. The utility benefits from reduced transmission and distribution costs.

2.6.2 Lessons learned about prosumer compensations

2.6.2.1 Defining the energy credits

The energy credits refer to the minimum between the grid-imported energy and PV-exported energy for the specified period. The cost relationship between them can be 1:1. Using Dufo-Lopez and Bernal-Agustín's (2015) approach, energy credits are calculated using four different situations; where there is no rolling period and no buy-back, where there is rolling period and buy-back, where there is a buyback, and where there is rolling credit [45].

2.6.2.2 The best practices for compensations

Roux and Shanker (2018) warn against penalizing the distribution company using larger values. To do this, the exported unit of electricity has to be less than or equal to the electricity generation average cost and compensation should only be for exported units. The other option is for the prosumer to be a net-importer in order to avoid the prosumer being an Independent Power Producer (IPP). Furthermore, the bi-directional meter should be the liability of the customer [11].

The countries/states with better net metering practices have tried to align the revenues to costs for their utility companies. Zummo (2015) gets into details and the findings are summarized below [14].

- At Lakeland in the United States, the demand rate of $4.80/kW for every month is payable by the residential customers. Every kWh of exported energy is credited at a reduced energy rate.
- The Whitehall city's utility, in the United States, compensates the prosumers at the wholesale rate (avoided costs) for every kWh of electricity injected into the grid. Here, the generation and consumption are treated differently as un-identical services each having different charges.
- The Santee Cooper utility in South Carolina, United States, has the monthly charges, on-peak, and off-peak demand charges. The energy credits to the prosumers are dependent on the time of use. Also, the energy charges incurred by prosumers are dependent on the time of use. However, seasonal on-peak is charged differently. Ultimately, the prosumers are given the wholesale electricity producers' treatment.
- At Concord Light in the United States, the utility pays energy credit from the prosumers at less than the retail price. The net metering tariff has an additional distribution charge that increases with the increasing size of the PV system. All the utility customers share distribution charges. The lowest monthly charge is set at $3.60 applicable for 2 to 4 kW PV system capacity.
- In Zimbabwe, the prosumers receive the credit of 0.9 kWh for every kWh injected into the grid within the billing duration. No monetary compensation claims are expected by participants. The billing period is on monthly basis. The distribution utility bills the net importers according to the standard rate schedule for the energy imported [46].
- South Africa has two different charges for different locations (0.06 to 0.12 USD/kWh is used by Nelson Mandel Bay and 0,05USD/kWh for eThekwini).
- On the contrary, Ghana allocates 1 kWh credit for each kWh. Prosumers do not get monetary compensations for their grid-injected energy.

From what other countries are doing, it is clear that the different countries charge differently. However, the compensation rate that is equal to average production cost cannot be used for Lesotho. This is because the production costs for PV-generated electricity are much higher than the current retail price of electricity due to the government subsidies for electricity. Possible rates are those charges greater or equal to the wholesale price but less than the retail price. Nevertheless, the charge should allow for utility costs recovery for distribution and administrative fixed costs.

There is a bit of a problem however. The type of electricity billing in Lesotho is prepaid. The customers pay for electricity units which they are yet to consume. The meter cuts the electricity supply once the purchased units are exhausted. Roux and Shanker (2018) indicate that for emerging countries they studied (Ghana and South Africa), the prepayment is not compatible with net metering [11]. This applies to Lesotho too. This means that the customers opting for net metering in Lesotho may be forced to remove the prepaid meters from their premises. On the utility side, there is a need to be capacitated for setting up the fresh billing system. The cash flow is also expected to change especially with longer billing periods for prosumers.

2.7 Net Metering Adoption strategies

Akhtar et al (2017) have two suggestions based on Net Metering Adoption strategies;

- The government should facilitate further revenue generation from investments by mitigating risk; facilitating regulation of PV systems and providing tax extension and incentives to encourage investment flows.
- The government should work hand in hand with the local institutions of research and international organizations to build net metering policies that are founded on evidence-based research [47]

Some factors affect the net-metered grid-connected PV systems' adoption rate as explained by Schelly et al (2017). The current electricity prices, the values of the potential net metering customers and solar irradiation available for the particular place of interest have an impact on the adoption rate [48]. This indicates that policy is not the only determinant of the adoption rate.

Chapter 3: Methodology

3.1 Designing net metering policy guidelines

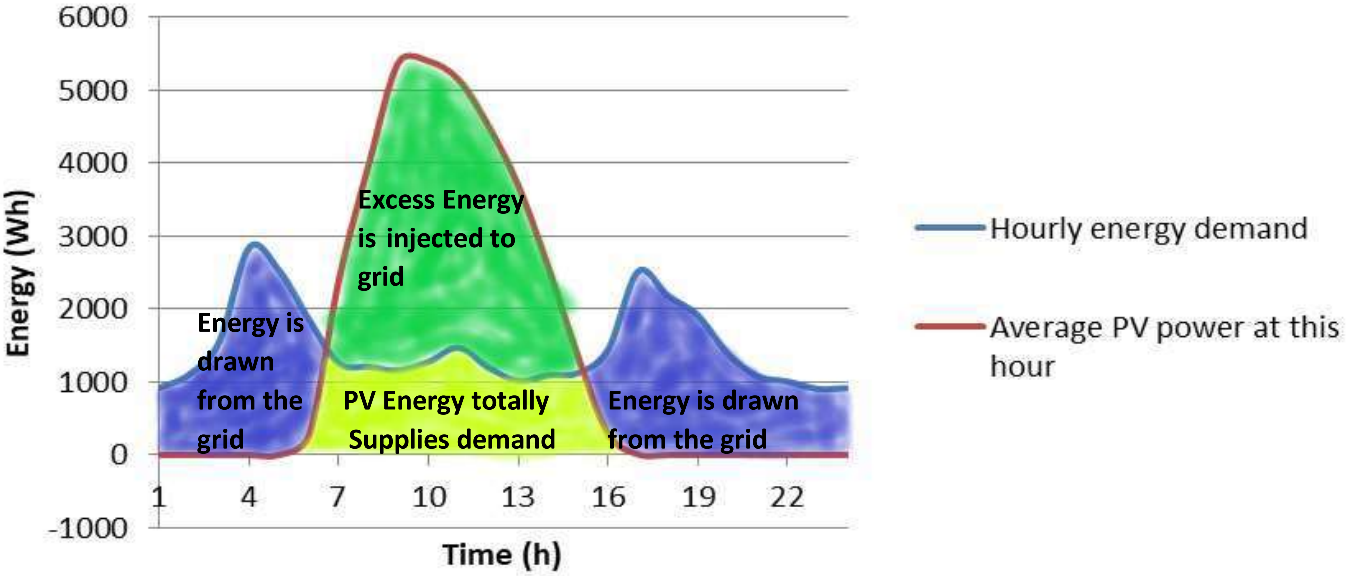


Figure 8: Showing the PV power and the load curve interaction

The net metering policy is dependent on the electricity prices because the retail prices can influence the success of the policy. Firstly, the policy option for this my study is such that the price of selling PV electricity to the grid is equal to the retail price of electricity from the utility. Like it is indicated earlier, Lesotho utility company (Lesotho Electricity Company) selling price for electricity is $0.017 per kilowatts for the industrial and commercial high voltage customers while for the residential customers is $0.10. The prosumer will be selling PV electricity to the utility at the same rates. This will help to avoid the potential cost shift (cross-subsidy) outlined in section 2.3.1. Again, this complies with Net Metering good practices outlined in section 2.6.2.2 such that the distribution company is not penalized.

Secondly, there is no capacity cap for the net metered PV system. The system sizing is done such that the area under the PV power curve is equal to the area under the load curve. This simply means the total annual energy generated from the PV system should be equal to the total annual load for the prosumer. This allows the customer of any load to participate in the electricity net metering process.

Thirdly, the net metering benefits are obtained from surplus energy sales from the PV system, the avoided energy savings and the peak power shaving where possible. These are indicated in Figure 8.

Fourthly, the billing period for the net metering customer is twelve months. This means that at the end of the financial year, the energy produced from the PV system should be equal to the energy obtained from the utility.

Most of the computations in the excel model and the subsequent sections will be based on these policy guidelines. The policy looks at the PV electricity net metering under both the customer and utility perspective.

Policy implications

There are three observable implementations of this policy.

- Many financially capable utility customers are likely to apply and participate in electricity net metering
- There is likelihood of off-loading the utility from the burden of importing to much electricity from the external utilities such as ESKOM and DEM
- Net metering still allows utility power to be bought which ensures survival of the utility.

3.2 Modeling of meteorological data

The Typical Meteorological Year (TMY) data closest to Maseru is identified to calculate the PV power output for each hour of the given typical year. Parameters used from this data are irradiation on the horizontal surface, diffuse radiation, ambient temperature, wind speeds and latitude of the location of the proposed PV system. These parameters are used to calculate the total radiation on the tilted solar module.

The beam radiation on the tilted surface is determined using the cosine of an angle of incidence (θ) that is calculated using the declination angle (δ), solar zenith angle (φ), tilt angle (β), surface azimuth angle (γ) and hour angle (ω) as shown on equation (5) [26].

The declination is calculated using equation 4.

$$\delta = 23.45\, Sin\left(\frac{360}{365}\ (n - 284)\right)$$ **Equation (8)**

An hourly position of the sun is calculated using equation 9.

$$\omega = 15(t - 12)$$ **Equation (9)**

The latitude angle is given by the line of latitude the place is located. In this case, Maseru town is located on latitude -29.3^0 while the solar azimuth is 180^0 since the solar panels will face due North and it is in the southern hemisphere. The best tilt angle for this location is obtained by adjusting the absolute latitude angle by 5^0 making it to be 34.4^0.

Using the above angles, the angle of beam radiation (θ) on the tilted solar panel is given by equation 10.

$$\cos\theta = \sin\delta \sin\varphi \cos\beta - \sin\delta \cos\varphi \sin\beta \cos\gamma + \cos\delta \cos\varphi \cos\beta \cos\omega + \cos\delta \sin\varphi \sin\beta \cos\gamma \cos\omega + \cos\delta \sin\beta \sin\gamma \sin\omega$$

Equation (10)

The cosine of a solar azimuth angle (θz) is calculated based on equation (10) to give the irradiation on the horizontal surface at any time of the day [27].

$$\cos\theta z = \sin\delta \sin\beta + \cos\delta \cos\varphi \cos\omega$$ **Equation (11)**

The ratio of **cos θ** to **cos** θz gives the geometric factor *Rb,* as indicated by the Equations (12).

$$R_b = \frac{\cos\theta}{\cos\theta z}$$ **Equation (12)**

The geometric factor can also be given in terms of the ratio of the difference between irradiation on the tilted surface and the diffuse irradiance to that of the difference between irradiance on the horizontal plane and the diffuse irradiance. Therefore equation 12 can be deduced to equation 13.

$$R_b = \frac{G_T - G_d}{G_h - G_d}$$ **Equation (13)**

G_T can be obtained by rearranging Equation 13 to obtain equation 14.

$$G_T = (G_h - G_d)R_b + G_d$$ **Equation (14)**

3.3 System Load modeling

The representative mean curves of both industrial and commercial activities obtained by Jardini et al (2018) can be used to construct the load profiles. The points on the y-coordinates of curves are jotted down and each point is divided by the sum of the points to convert the points to decimal numbers that can be used to distribute the hourly loads while maintaining the shape of the load profile. A similar approach has been also used by Tazvinga and Hove (2017) to draw the representative load profiles for residential

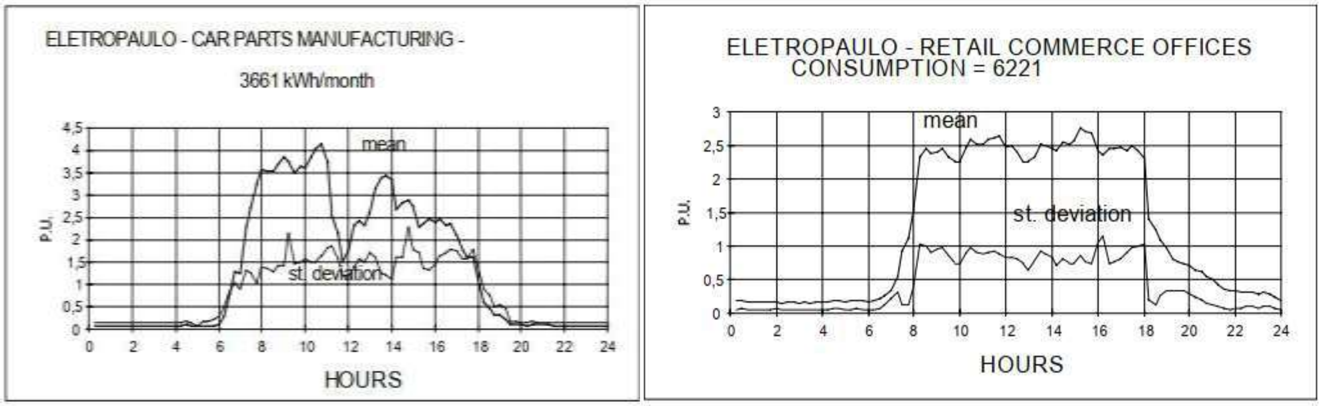
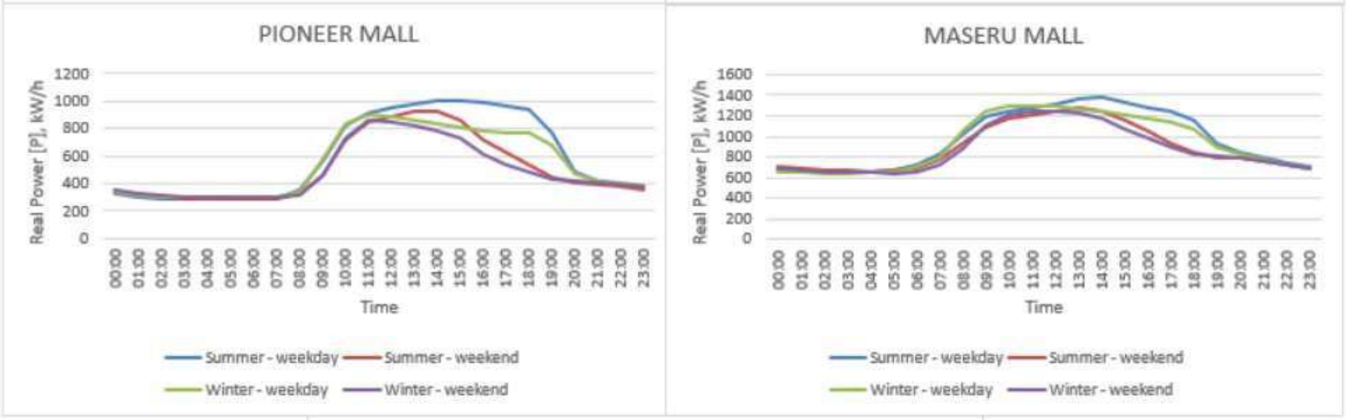


Figure 9: The representative curves for industrial and commercial activities

Activities [49]. Mpholo et al (2021) also produced similar load demand profiles to the ones given by the utility for high voltage customers as shown in Figure 9 [50].

High voltage utility's customers



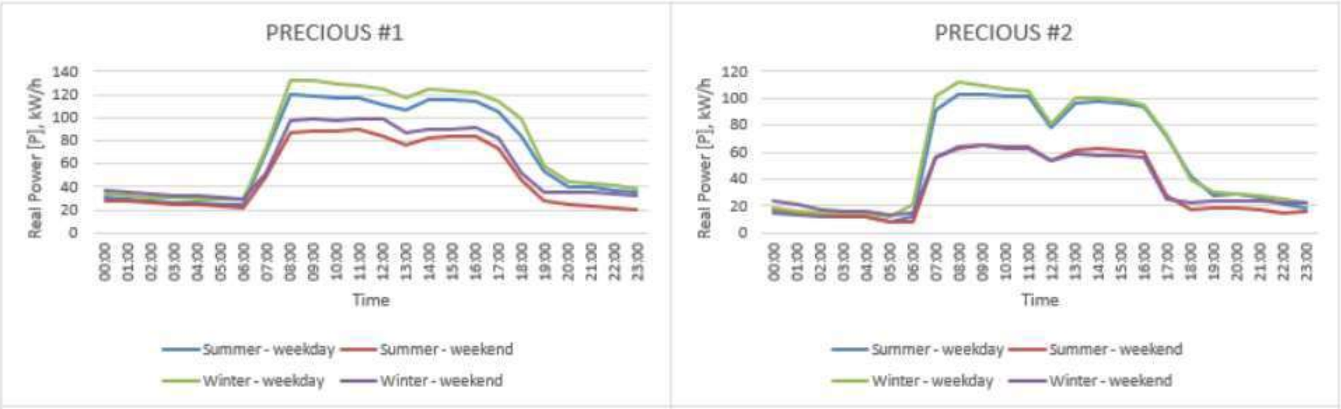


Figure 10: The commercial and industrial high voltage customers' load demand profiles

From Figure 10, the two different commercial customers have similar load demand profiles and likewise for the industrial customers.

3.2.1 Using typical load profiles from Utility (LEC)

Using the typical hourly load profiles provided by the utility (LEC) for three customer categories, the load is varied for different customers in the same categories and the results of the proposed systems are obtained. The shapes of these load profiles resemble those obtained by Jardini et al (2018). There is the time of the day when the daily demand is minimum or maximum. The maximum hourly demand is used as the basis of the proposed PV system capacity. The analysis of these profiles is used to optimize the PV system power output to suit the specific application with variable or constant power load.

3.2.2 Creating Customer load profile

The 30 minutes interval consumption data for the industrial, commercial and residential utility customers is obtained and converted to the hourly consumption in kilowatt-hour for a year using combinations of summation and offset functions in excel. The results are then fed into the excel model as the hourly load for the whole year. The model calculates and gives the results as shown in the following chapter. As for the residential load profile, the typical load profile data was given from the utility.

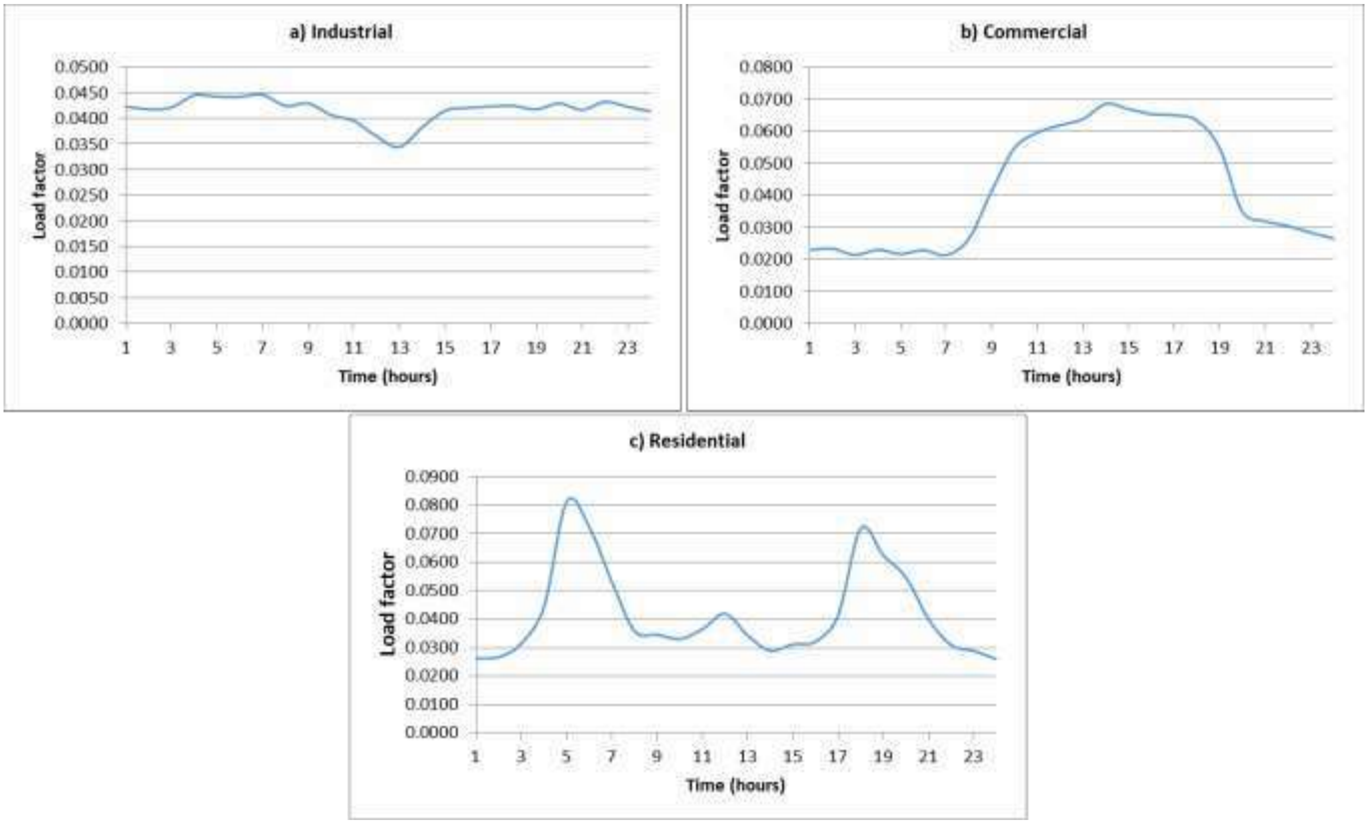


Figure 11: Typical load demand profiles for three customer categories

3.3 System sizing

Sizing the system components is done on an inverter for alternating current (AC) and PV modules for direct current (DC).

3.3.1 Modeling the PV modules

The system PV array power is modeled based on annual energy demand of the client after considering inverter losses. This is attained by using goal seek function in excel model to vary the PV array power while setting the total annual generated energy to be equal to the total annual generated energy. Hence the PV array power from the selected solar module should be able to supply enough power for the self-consumption of the system owner. This is helpful to acquire an optimal number of solar modules to produce sufficient power.

The PV modules are connected in series and/or parallel depending on the required voltages and current for the PV system. An array of PV modules is made by connecting the modules in series to attain the maximum voltage required for the serial connection. The arrays can be connected in parallel to obtain the maximum current for the system. For the optimized incident solar radiation received by solar modules, the modules are mounted such that they are tilted at 34^0 for the location under study.

3.4 Performance predictions of a solar PV plant

The prediction is done for two adverse seasons (winter and summer) for Lesotho. The variation in performance is calculated in percentage. The technical calculations involve the following parameters;

3.4.1 System field efficiency

Three types of efficiencies used are PV efficiency, inverter efficiency, and system efficiency

The field efficiency can also be obtained directly by the following model used by Hove (2000) on the following formula on equation 15.

$$\eta_{PV} = \eta_r \left[1 - 0.9\beta \frac{G_T}{G_{T,NOCT}} \left(T_{C,NOCT} - T_{a,NOCT} \right) - \beta \left(T_a - T_r \right) \right]$$

Equation (15)

3.4.2 PV modules power

The PV module power output under the field conditions can be determined.

For time-step energy simulations, it is convenient to model the instantaneous PV generator power output, P_{PV} as:

$$P_{PV} = \frac{\eta_{PV}}{\eta_{STC}} \cdot \frac{G_T}{G_{STC}} \cdot P_{STC}$$

Equation (16)

Where:

η_{PV} is the instantaneous cell-temperature-dependent PV efficiency η_{STC} is the PV efficiency at standard test conditions (STC)

G_T is the solar irradiance incident on the plane of the PV array/module G_{STC} is the in-plane incident solar irradiance at standard test conditions

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

It is important to note that this PV power uses direct current therefore it can be denoted as the PV (dc) power which is fed into the inverter.

According to Virtič and Lukman (2019), the peak power of the highly cost-effective PV system associated with net metering (P_{PV_CE}) is given by equation 17 [53].

$$P_{PV\_CE} = \frac{E_{cons}}{E_{prod}} \cdot P_{PV}$$ **Equation17**

Where E_{cons} is the energy consumed per annum, E_{prod} is energy produced per annum, P_{PV} is the peak power of the current PV system. The policy guideline opted is in line with this equation since the area under the load curve is equal to the area of the under the PV generated power as indicated in section 3.1 above.

3.4.3 The inverter power

According to Azhan et al (2019), the inverter efficiency is just the ratio of the inverter output (ac) power to the PV input (dc) power [54]. The inverter output power varies with changing PV power fed in. The output power (P_{INV}) from the inverter is denoted by equation 18.

$$P_{INV} = \eta_{INV,STC} \cdot \frac{P_{PV}}{P_{PV,Rated}}$$ **Equation (18)**

Where P_{PV} is the PV power produced and $P_{PV,\ Rated}$ is the rated power of the inverter required. η_{INV} is the inverter efficiency.

The chosen inverters for three utility clientele are SUNNY BOY 6.0-1SP-US-41, SUNNY TRIPOWER CORE1 (STP 50-40), and Sungrow 110kw Grid-Tied (SG110CX) for residential, commercial and industrial purposes respectively. Their power curves are shown in Figure 12.

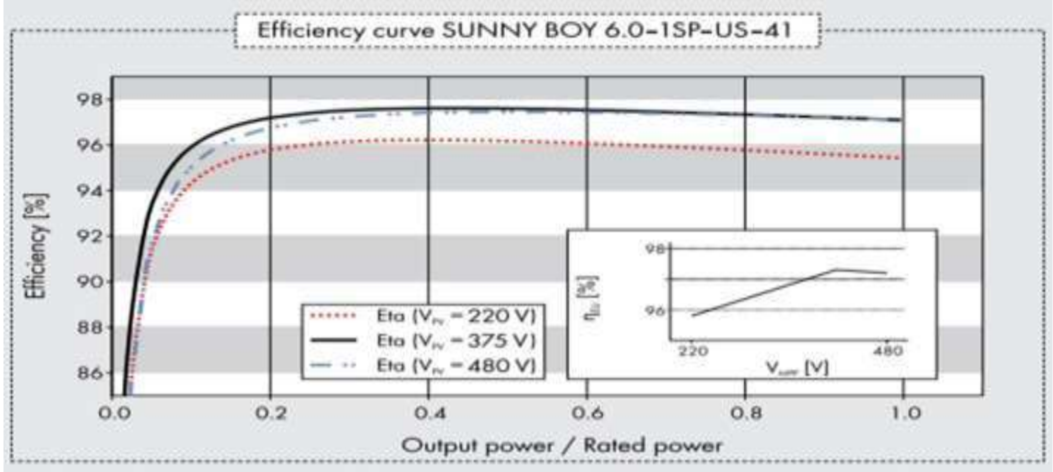
3.4.3.1 Calculation of Inverter Power

The efficiency curves for three types of inverters are obtained. The 220V and 850V for DC are chosen for residential and industrial inverters respectively. The recalibration is done to make the readings easier on the curves. The curve is divided into regions according to the shape and then the points are jotted down for each region. For every region, the chart showing the corresponding trend lines for the points are inserted and their equations are extracted as shown in Table 6. The equations are inserted into the excel model to define the changing efficiency with changing ratio of actual inverter power over the rated power.

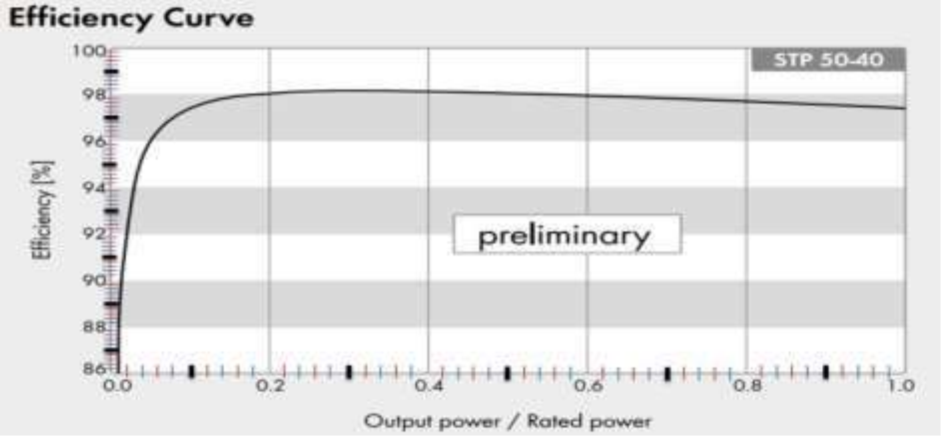
Table 6: Regions, points, and equations describing the inverter efficiencies

Power/Rated Power Range		Efficiency Equations
Residential: Sunny Boy 6.0-1SP-US-41		
Region1	0.02 to 0.1	y = -1571.4x2 + 300.57x + 79.72
Region2	0.12 to 0.2	y = 12x + 93.44
Region3	0.22 to 0.38	y = 1.5x + 95.65
Region4	0.42 to 0.98	y = -1.4606x + 96.891
Commercial: Tripower Core1 (STP 50-40)		
Region1	0.02 to 0.1	y = -1000x2 + 185x + 88.9
Region2	0.14 to 0.38	y = -16.369x2 + 9.7619x + 96.759
Region3	0.4 to 1	y = -1.1786x + 98.596
Industrial: Sungrow 110kw Grid Tied (SG110CX)		
Region1	0.05 to 0.22	y = -109.36x2 + 44.044x + 93.969
Region2	0.22 to 0.36	y = 1.0006x + 0.1399
Region3	0.36 to 0.99	y = -0.2991x + 98.688

SUNNY BOY 6.0-1SP-US-41



SUNNY TRIPOWER CORE1 (STP 50-40)



Sungrow 110kw Grid Tied (SG110CX)

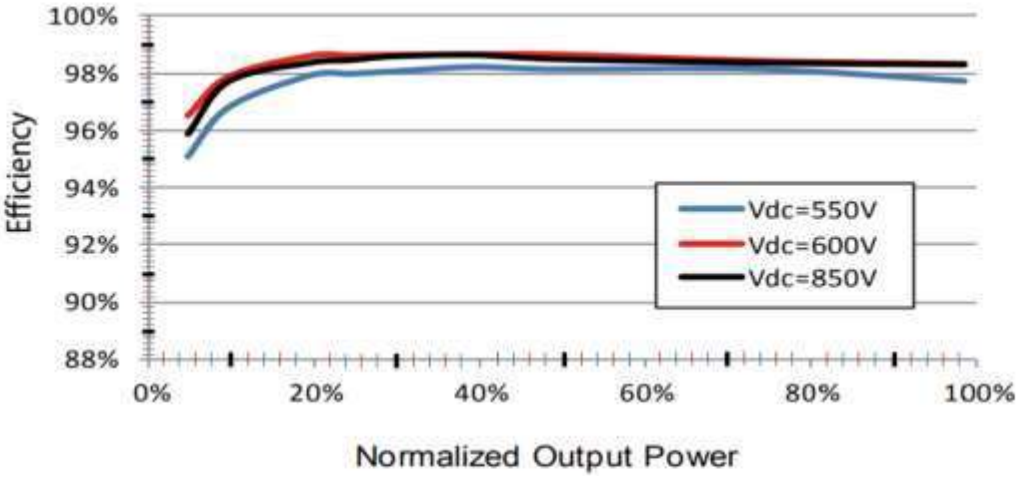


Figure 12: The inverter efficiency curves for commercial PV system

The trendline of the regions on SUNNY TRIPOWER CORE1 (STP 50-40) inverter

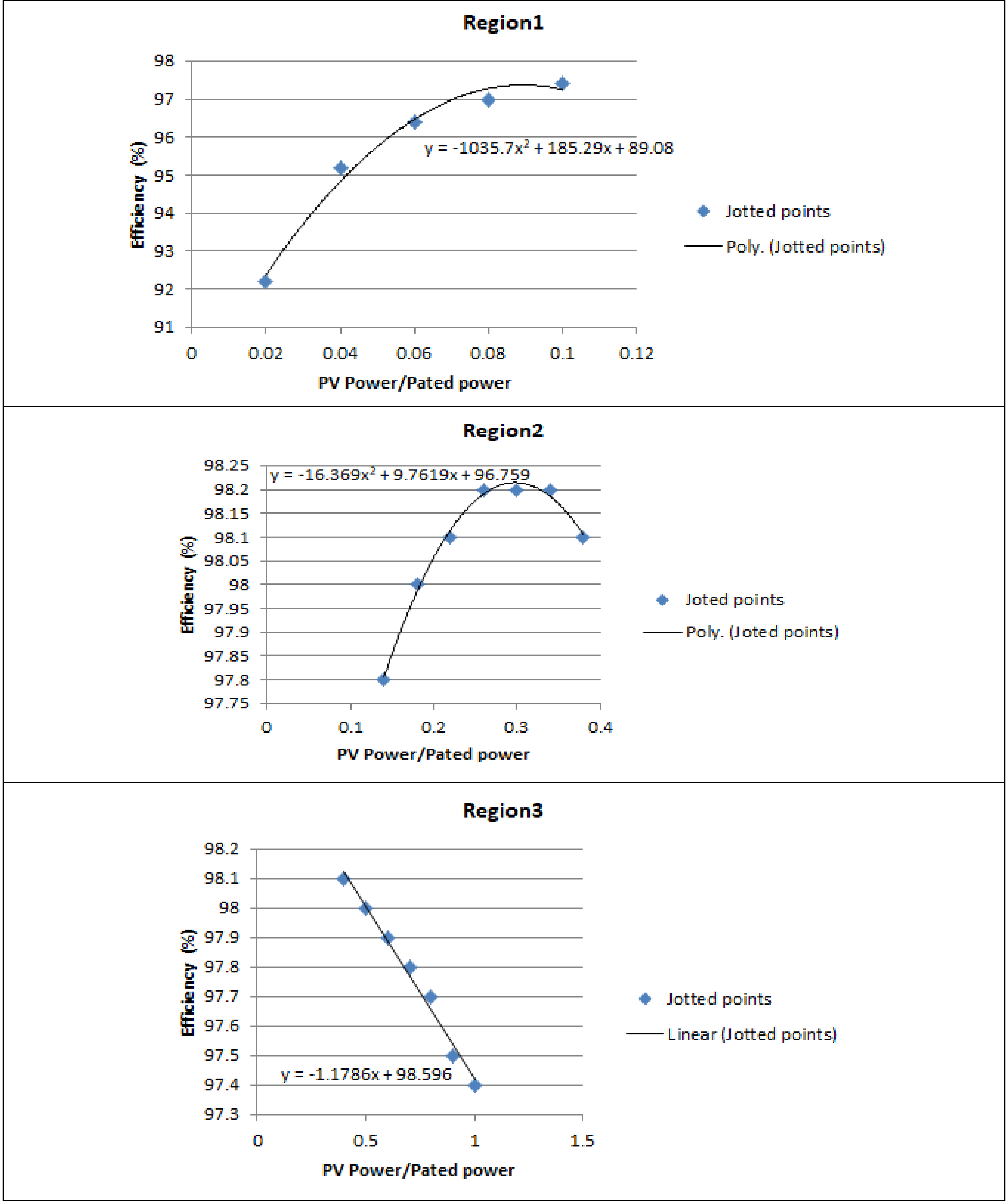


Figure 13: Regions describing the inverter efficiencies for commercial PV system

A similar approach is used for inverters selected for both residential and industrial.

3.4.3.2 The PV array power

The PV array power should be enough to give the total power sufficient for the annual load. The annual load for each client category is used to estimate the PV array power anticipated. The goal seeks method in excel is used to perform the calculations. While setting the annual power generated to equal the annual load, the PV array is varied and finally, the required PV array is obtained.

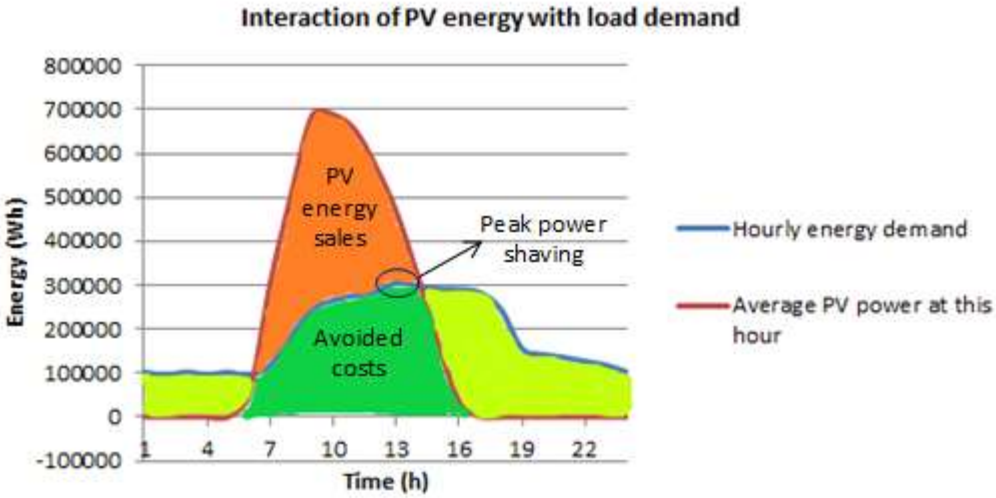


Figure 14: Showing three net metering benefits

3.4.3.3 Calculation of net metering benefits

There are three benefits possible for this system as shown on Figure 14. i) The energy sales, ii) Avoided costs of energy, iii) Peak power shaving possibility for the big utility customers.

Avoided costs of energy

The installed PV system generates energy that replaces the utility's energy during the solar hours. Every unit used from the PV system is the avoided energy obtainable from the grid whose costs are computable. In this way, the periodical avoided costs of using energy can be summed up and this is a benefit to the prosumer.

The avoided costs are set under only two conditions. 1) If the load is greater than or equal to the PV energy, then avoided energy becomes PV energy. 2) If the load is less than the PV energy, the load becomes the avoided energy. With either of the two conditions satisfied, the avoided energy that is indicated by green is multiplied by the retail price of energy to get the avoided cost of energy.

Energy Sales

Depending on the weather conditions and seasons, PV systems can generate more power than the load. In this case, the extra power is sent to the grid. Every unit of power injected is measured and considered sold to the utility. The excel expression is shown in equation18

Energy to the grid (kWh) * tariff ($)= Energy sales **Equation18**

In the model if the inverter power is less or equal to the load, then there is no excess that can be injected into the grid. But if the inverter power is greater than the load, then the difference is the surplus energy that can be injected to the grid. This surplus energy is multiplied by the cost of electricity to obtain the energy sales. In this way the prosumer has sold electricity to the utility.

Peak power shaving benefits

More energy is drawn from the utility grid during peak hour demand. But if the PV power is produced during the peak hour demand, then less energy is drawn from the grid. This is called the peak power shaving. In the model, the total days in each month are multiplied by twenty-four (24) hours to the total number of hours in that month. The total of those hours is used to define the monthly range in the excel model to return the maximum energy demand for that particular month. The maximum value is multiplied by the demand charge. If the peak demand is reached during the peak solar hours, then the presence of PV power reduces the demanded energy hence the prosumer pays less or ends up not paying the demand charge at all. It is important to understand that the peak power shaving may or may not be experienced. It depends on the time of the day. If the peak consumption is at night, or if it happens during the bad weather when PV power is less than the load, then the peak shaving will not happen. Therefore at times it becomes difficult to calculate the peak power shaving benefit for the customer.

3.5 The utility and prosumer Revenues calculations

Utility's Revenue

The revenue of the utility if the PV system is not installed is made from the sales of grid energy. But with the installed PV system, the utility has four revenues generation sources; i) the avoided costs (A_c) which the utility is supposed to incur to secure the energy if the PV system is not generating power for the prosumer, ii) the sales of energy to the prosumer during off-solar hours. Equation 19 shows the utility's revenue (U_R),

iii) the peak demand charge (P_D) applicable for commercial and industrial high voltage customers.

$$\boldsymbol{U_R = A_C + P_D +} \textbf{ Sales} \qquad \textbf{Equation (19)}$$

Prosumer’s Revenue

The prosumer is able to generate revenues from the savings from i) avoided costs of buying electricity from the utility (A_{CU}), ii) avoided Peak demand savings (P_{Ds}) and iii) the excess energy sales (E_S).

Equation 20 shows the components of the prosumer‟s revenues (P_R).

$$\boldsymbol{P_R = A_{CU} + P_{Ds} + E_S} \qquad \textbf{Equation (20)}$$

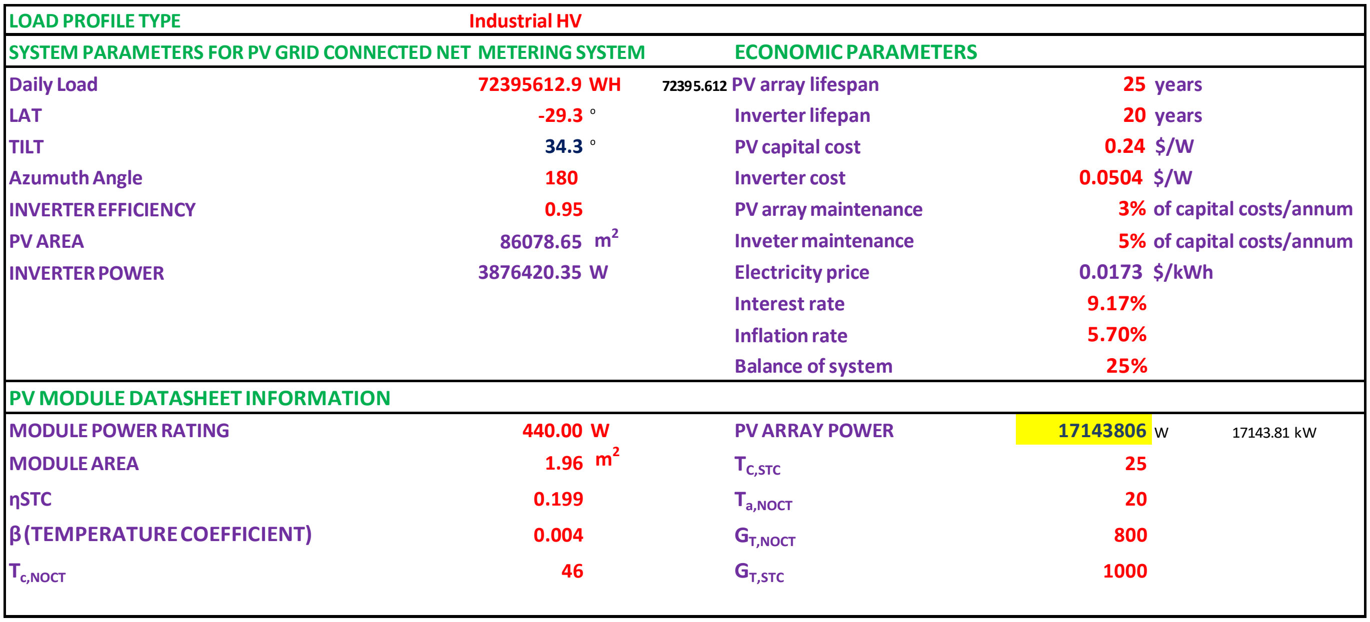
Energy credit is the PV injected energy that is consumed by the grid (positive value of PV energy minus grid energy). The power losses credit

3.6 Modeling System's components

3.6.1 Modeling System inputs' interface

Table 7 shows the user interface for the constructed excel model. The input parameters are categorically put for ease of use. The inputs include economic data, PV module parameters from the module datasheet and the prosumer daily load amongst others.

Table 7: The user interface for the excel model



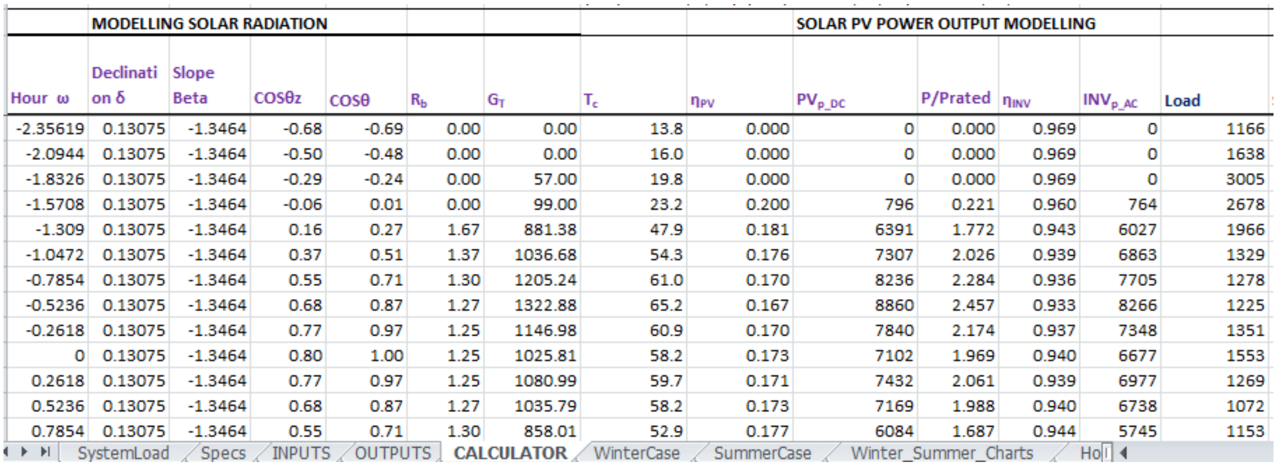
LOAD PROFILE TYPE	Industrial HV						
SYSTEM PARAMETERS FOR PV GRID CONNECTED NET METERING SYSTEM				ECONOMIC PARAMETERS			
Daily Load	72395612.9	WH	72395.612	PV array lifespan	25	years	
LAT	-29.3	°		Inverter lifepan	20	years	
TILT	34.3	°		PV capital cost	0.24	$/W	
Azumuth Angle	180			Inverter cost	0.0504	$/W	
INVERTER EFFICIENCY	0.95			PV array maintenance	3%	of capital costs/annum	
PV AREA	86078.65	m^2		Inveter maintenance	5%	of capital costs/annum	
INVERTER POWER	3876420.35	W		Electricity price	0.0173	$/kWh	
				Interest rate	9.17%		
				Inflation rate	5.70%		
				Balance of system	25%		
PV MODULE DATASHEET INFORMATION							
MODULE POWER RATING	440.00	W		PV ARRAY POWER	17143806	W	17143.81 kW
MODULE AREA	1.96	m^2		$T_{C,STC}$	25		
ηSTC	0.199			$T_{a,NOCT}$	20		
β (TEMPERATURE COEFFICIENT)	0.004			$G_{T,NOCT}$	800		
$T_{c,NOCT}$	46			$G_{T,STC}$	1000		

Calculated parameters are; the PV area required for the modules, tilt angle which is dependent on the line of latitude and the PV array power that can satisfy the peak demand of the customer.

3.6.2 Processing unit

This component uses equations 5 to 18 resulting final energy calculation. Table 8 shows the portion of the resulting values from the inserted equations to simulate the performance of the proposed solar PV plant that is connected to the grid.

Table 8: The portion of excel model processing unit



	MODELLING SOLAR RADIATION								SOLAR PV POWER OUTPUT MODELLING				
Hour ω	Declination δ	Slope Beta	COSθz	COSθ	R_b	G_T	T_c	η_{PV}	PV_{p_DC}	P/Prated	η_{INV}	INV_{p_AC}	Load
-2.35619	0.13075	-1.3464	-0.68	-0.69	0.00	0.00	13.8	0.000	0	0.000	0.969	0	1166
-2.0944	0.13075	-1.3464	-0.50	-0.48	0.00	0.00	16.0	0.000	0	0.000	0.969	0	1638
-1.8326	0.13075	-1.3464	-0.29	-0.24	0.00	57.00	19.8	0.000	0	0.000	0.969	0	3005
-1.5708	0.13075	-1.3464	-0.06	0.01	0.00	99.00	23.2	0.200	796	0.221	0.960	764	2678
-1.309	0.13075	-1.3464	0.16	0.27	1.67	881.38	47.9	0.181	6391	1.772	0.943	6027	1966
-1.0472	0.13075	-1.3464	0.37	0.51	1.37	1036.68	54.3	0.176	7307	2.026	0.939	6863	1329
-0.7854	0.13075	-1.3464	0.55	0.71	1.30	1205.24	61.0	0.170	8236	2.284	0.936	7705	1278
-0.5236	0.13075	-1.3464	0.68	0.87	1.27	1322.88	65.2	0.167	8860	2.457	0.933	8266	1225
-0.2618	0.13075	-1.3464	0.77	0.97	1.25	1146.98	60.9	0.170	7840	2.174	0.937	7348	1351
0	0.13075	-1.3464	0.80	1.00	1.25	1025.81	58.2	0.173	7102	1.969	0.940	6677	1553
0.2618	0.13075	-1.3464	0.77	0.97	1.25	1080.99	59.7	0.171	7432	2.061	0.939	6977	1269
0.5236	0.13075	-1.3464	0.68	0.87	1.27	1035.79	58.2	0.173	7169	1.988	0.940	6738	1072
0.7854	0.13075	-1.3464	0.55	0.71	1.30	858.01	52.9	0.177	6084	1.687	0.944	5745	1153

3.7. PV Energy Production

The calculated hourly PV power generation is compared to the hourly load profiles for residential, industrial and commercial systems. If the hourly PV power generation exceeds the consumption, it is assumed that the excess is injected into the grid. This is represented by the region shaded green in Figure 15. Else, if the generated PV power is lower than consumption, then the deficit power is assumed to be drawn from the utility grid as shown on the region shaded blue. At peak sunshine hours, the PV system can supply a hundred percent of the load demand and this is shown by the yellow shaded region. The map of annual generation is provided for the three different generation systems and the profitability of the systems is analyzed. The net consumption in each system is multiplied by the electricity retail price as stated by Lesotho Electricity and Water Authority (LEWA). This approach has been used by Vaishnav et al (2017) [51].

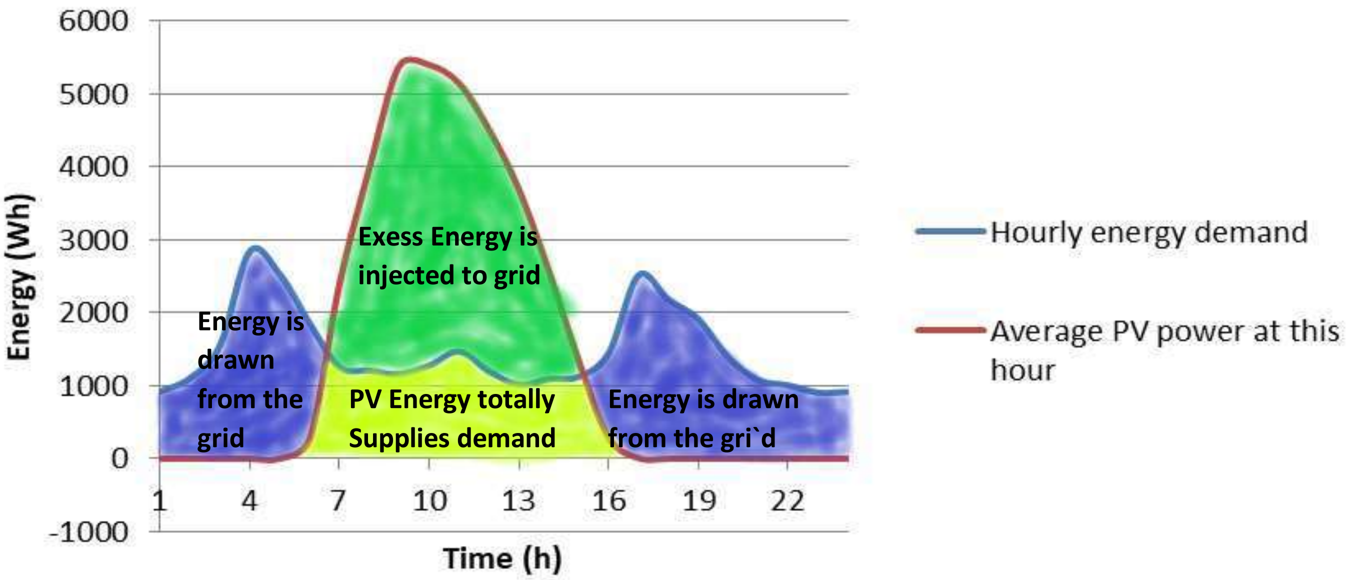


Figure 15: The interaction of Load demand with PV power generation

3.8 Economic analysis

The optimal system parameters such as Levelized Cost of Electricity (LCOE), internal rate of return (IRR) and Net Present Value (NPV) are calculated. The costs of the solar panels, the inverter and bidirectional meter are obtained based on their current value on the market.

The cost and benefit analysis is done based on the fixed costs such as transmission and distribution costs and administrative charges incurred by the utility.

3.8.1 Cost of system components

The cost of solar modules and inverter is obtained from Alibaba.com in the form of cost per kilowatt. These are taken as the inputs into the simulation model system. Mostly, the prices at Alibaba are more cost-effective than local prices even if they include the shipping costs.

3.8.2 Selection of System components

The inverter and module selection is based on the latest technology due to improved efficiency. The size of the inverter is at least adjusted by 20% more than the PV output (ac) power to avoid the maximum performance of the inverter which may lower its life span.

3.9 System Setup

3.9.1 **Representative load curves**

The typical load profiles for three utility's customers are obtained from the utility. The resultant representative curves for typical load profiles of three utility customers are shown in Figure 16.

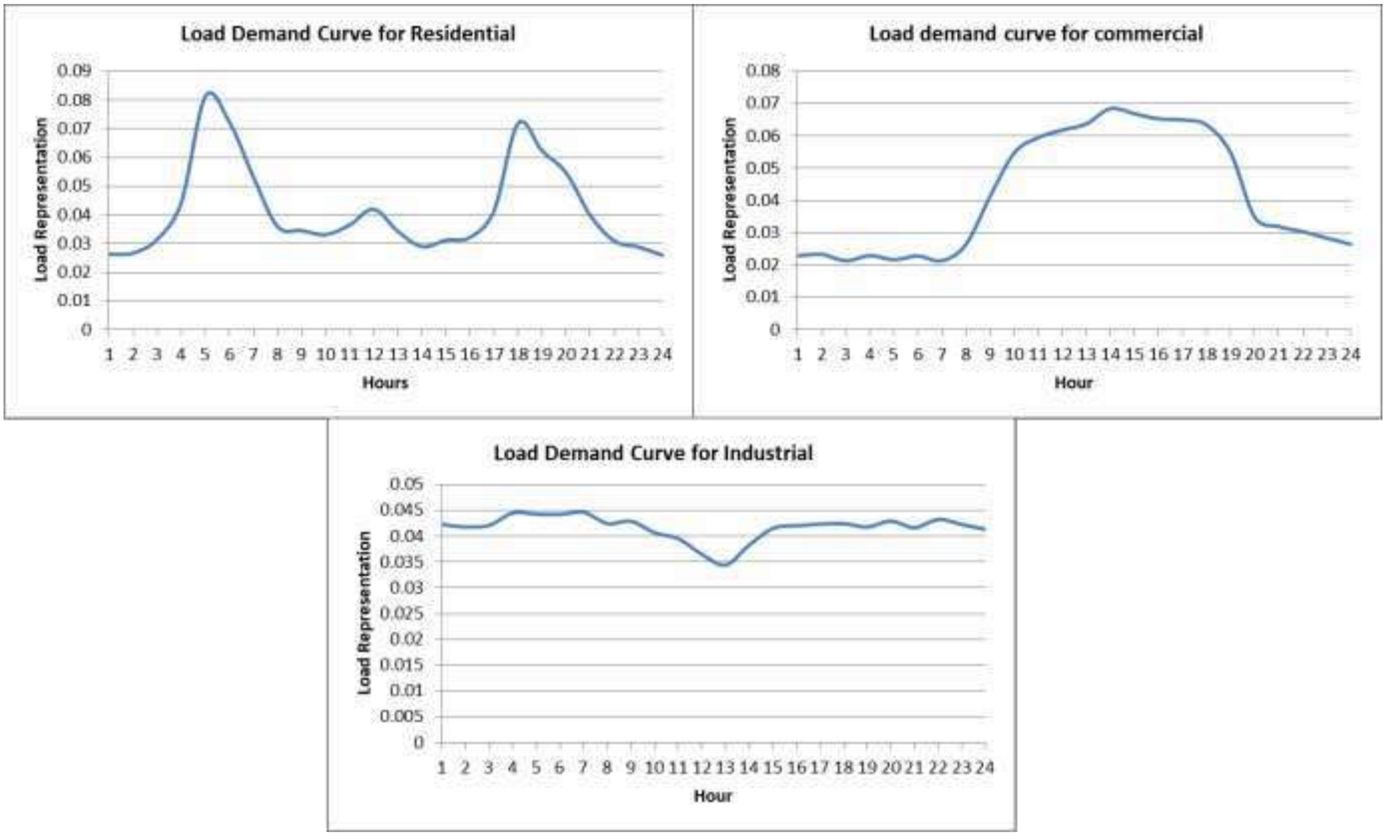


Figure 16: The representative load profiles curves for three utility customers

The shapes of these curves are used to distribute the daily load according to the typical consumption activities expected for the customer. The two peaks on the residential load profile curve are experienced in the morning hours at around 5 am when the household is preparing for the beginning of the new day before work and school time. The other peak is experienced around 6 pm when preparing for supper and dish washing activities for the typical household, after which only the lights are likely to be consuming energy for the rest of the night.

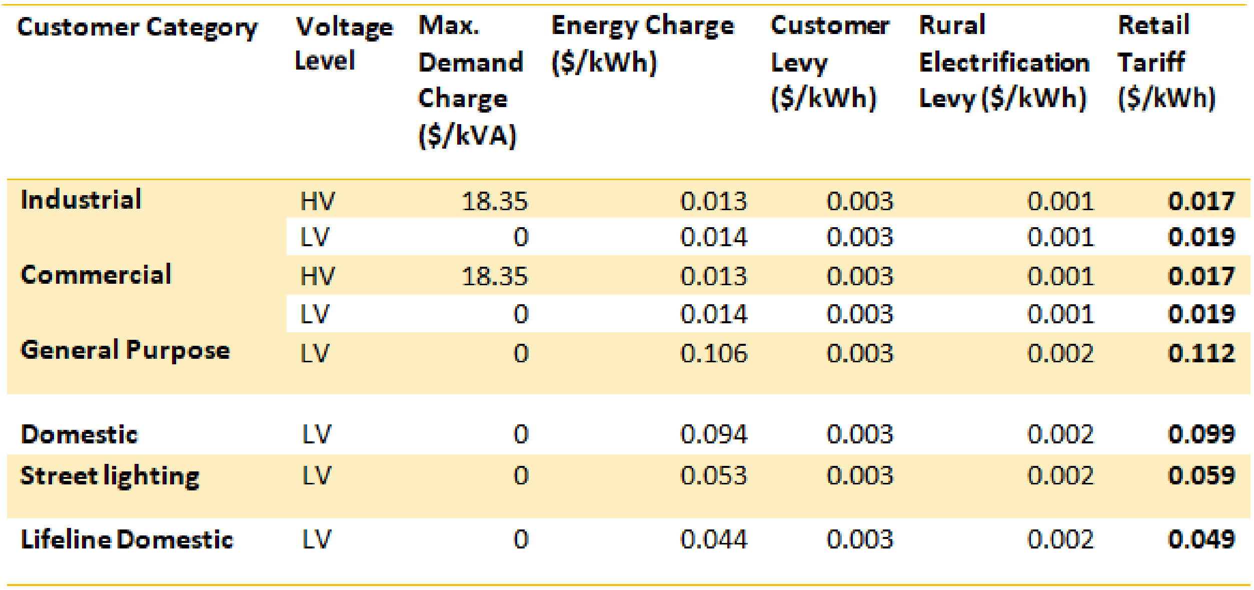
The industrial activities causing the shape show switching on and off some of the machinery used during the day. At around 5 am, most machinery consuming more energy becomes active for the workers to start their daily routines. The workers' lunch starts at around noon when most machinery is left idling hence the drop of consumption until 1 pm when they resume working. Most of the motors keep running day and night due to changes in working shifts.

For the case of commercial activities, most energy-consuming items are turned on at around 7 am until 12 am when consumption reaches the peak. Most of the commercial institutions such as supermarkets close from 6 pm to 8 pm.

3.9.2 The resultant tariffs

The calculated values for both import and export tariffs for prosumers are shown in Table 7. Eight categories of utility customers are indicated where highest import tariff for low voltage general purpose customers buying electricity is M1.66 ($0.11) per unit. For the purpose of this study, the prosumer pays M0.14 ($0.01) for industrial high voltage activities, M0.26 ($0.02) for commercial high voltage activities and M1.48 ($0.10). The compensation for the energy exported to the grid is M0.06 ($0.004) applying for either industrial or commercial and M0.42 ($0.03) per unit for residential.

Table 9: The values of components of tariffs applicable to the prosumers



Customer Category	Voltage Level	Max. Demand Charge ($/kVA)	Energy Charge ($/kWh)	Customer Levy ($/kWh)	Rural Electrification Levy ($/kWh)	Retail Tariff ($/kWh)
Industrial	HV	18.35	0.013	0.003	0.001	**0.017**
	LV	0	0.014	0.003	0.001	**0.019**
Commercial	HV	18.35	0.013	0.003	0.001	**0.017**
	LV	0	0.014	0.003	0.001	**0.019**
General Purpose	LV	0	0.106	0.003	0.002	**0.112**
Domestic	LV	0	0.094	0.003	0.002	**0.099**
Street lighting	LV	0	0.053	0.003	0.002	**0.059**
Lifeline Domestic	LV	0	0.044	0.003	0.002	**0.049**

The retail tariffs used for this study are $0.017 for both commercial and industrial high voltage customers and $0.099 for domestic or residential low voltage customers as shown on Table 7.

3.10 Assumptions involved

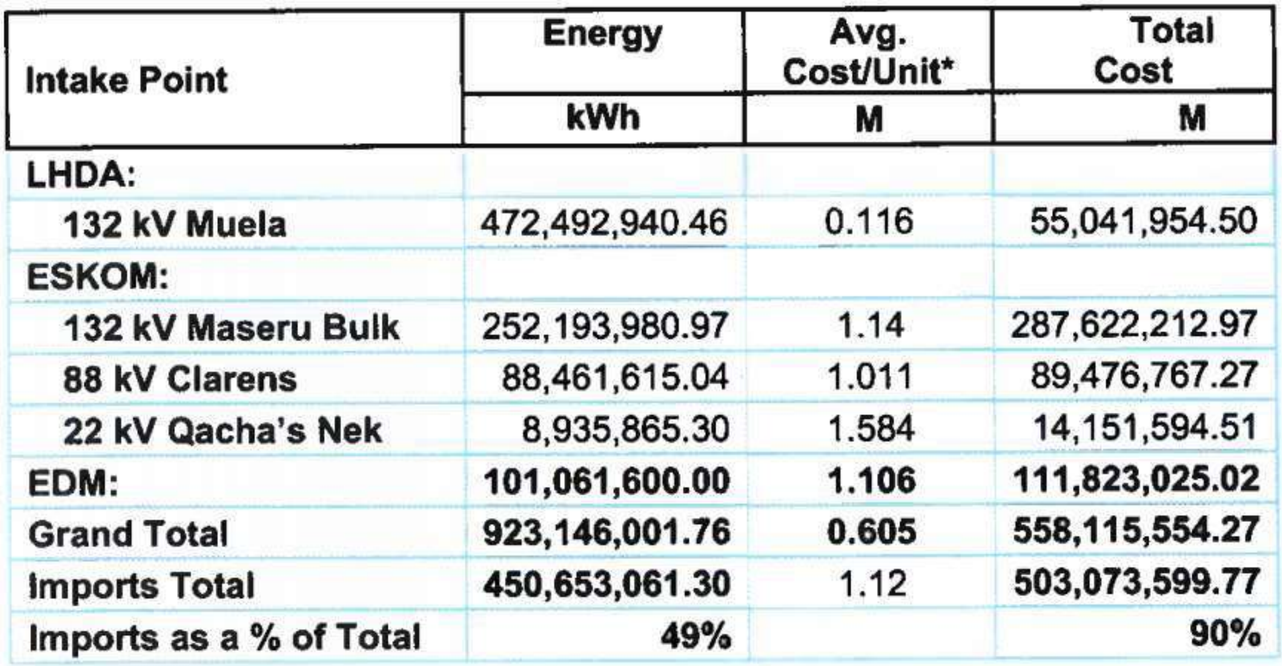
3.10.1 The monetary credits value

The monetary credits for excess energy injected into the grid are at the retail rate shown on **Table2** and **Table6** so that the net balance of buying and selling electricity is zero at the end of the billing period.

3.10.2 Utility fees for bulk purchases

LEC as only Lesotho's utility company is currently supplied by two utility companies outside the country. These are EDM and ESKOM from Mozambique and South Africa respectively. The local supplier is 'Muela. **Table7** shows the average cost of electricity from the three suppliers per unit in Maluti. The average ESKOM charge of \$0.084 (M1.245) is used in the computations within the model because it has the highest charge of the two.

Table 10: Forecasted bulk supply purchases by LEC 2020/2021 showing cost per unit (LEWA,2020)



Intake Point	Energy	Avg. Cost/Unit*	Total Cost
	kWh	M	M
LHDA:			
132 kV Muela	472,492,940.46	0.116	55,041,954.50
ESKOM:			
132 kV Maseru Bulk	252,193,980.97	1.14	287,622,212.97
88 kV Clarens	88,461,615.04	1.011	89,476,767.27
22 kV Qacha's Nek	8,935,865.30	1.584	14,151,594.51
EDM:	**101,061,600.00**	**1.106**	**111,823,025.02**
Grand Total	**923,146,001.76**	**0.605**	**558,115,554.27**
Imports Total	**450,653,061.30**	1.12	**503,073,599.77**
Imports as a % of Total	**49%**		**90%**

The injection of excess energy into the grid from the PV system causes the interaction that has not been charged by the utility. The prosumer may be liable for the use of service charges that includes capacity reserve, renewable energy source fund and the grid interaction fees. The values of these charges are assumed and allocated as shown in Table.

Chapter 4: Results and Discussion

The performance of the system is analyzed in terms of performance ratio and the results are shown in section 4.1. The simulation results for the proposed net-metered PV systems for residential daily consumption of 37 kWh is used and 4.5 MW consumption for both commercial and industrial are used. The residential PV system is composed of 18 modules each rated 440W with a 6kW inverter. This residential system generates 13.5 MW per year. The annual avoided energy is 4.1 MW while the energy sold to the grid is 9.4MW. From Figure 15, implementation of this system allows 18% of the energy from the grid to be avoided or saved for other users who are not participating in net metering. The total energy that is sold to the grid is equivalent to the total energy that is purchased from the grid which is 41% every year in this case. This means that the grid is used for energy storage by the net-metered PV customer.

The commercial PV system is composed of 2146 solar panels each rated 440W with the 50kW inverter. The system generates 1628MW annually, 742.6 MW (30%) is avoided and 885.6MW (35%) is sold to the grid while 214.8 kW is shaved from the peak demand. The commercial prosumer tends to have the total avoided energy of up to 30% every year. However, this energy is expected to drop annually throughout the life time of the project due to degradation of system components such as solar modules as Hernanda (2018) indicated.

The industrial PV system is made from 2135 solar modules each rated 440W and the inverter rated 110kW. The system generates 1628MW per annum, 541MW (20) is avoided and 1087MW (40%) is sold to the grid. There is no peak shaving for this system because the peak consumption of the customer is not happening during the peak generation of the PV power. The economic benefits from these systems are discussed in the section 4.2.

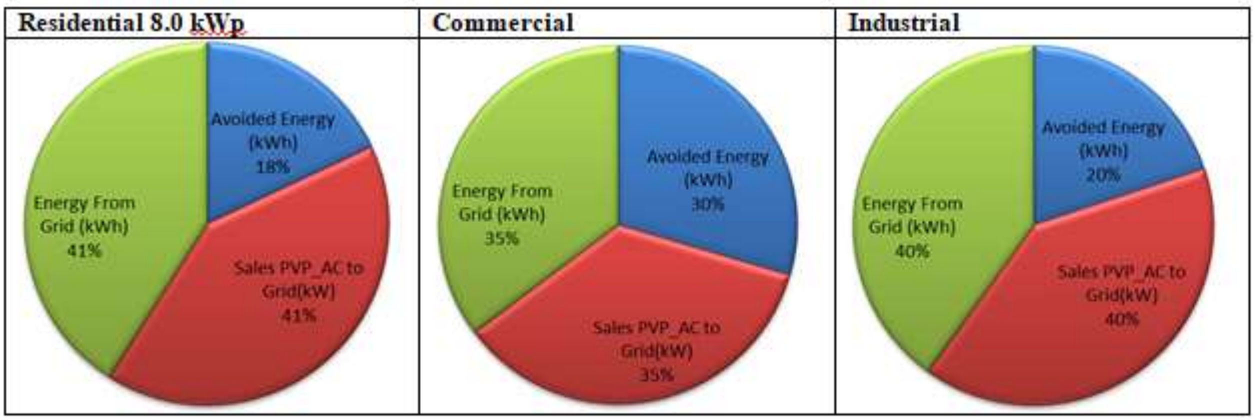


Figure 15: The annual energy balance for three customer categories

4.1 System performance

With reference to Figure 18, the simulation of a PV system with a capacity of 8 kWp serving the daily load of 37kWh starts generating power at 6 am. As more solar irradiation (G_T) is received on the tilted solar module, more power is produced until 9 am when production has reached the peak. There is a reduction of power from the inverter which is observable during the peak hours that is caused by reduced efficiency and some losses. According to the results, the used solar modules are capable of absorbing 71% of the total irradiation per year. The losses agree to the literature as stated by Vidyanandan (2017). 29% loss is caused by the variation in solar irradiations, module temperature and the tilt angle of the module.

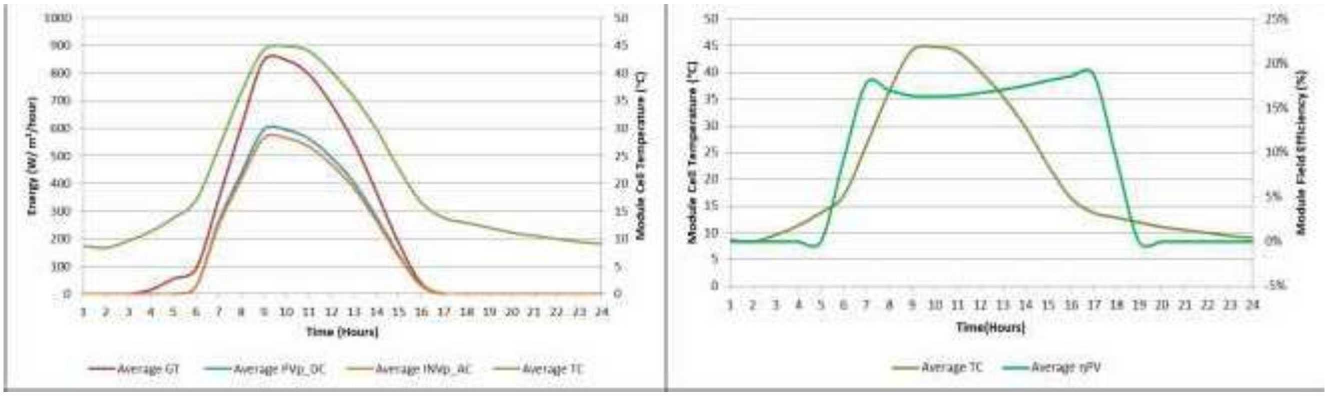


Figure 16: Hourly energy production and field efficiency vs module temperature

With reference to figure 18, the field efficiency of the solar modules during the peak hour of irradiation is only 16% for residential and 18% for both commercial and industrial systems at the module cell temperature of 45°C. This tells us that at high temperatures during high irradiance on the tilted module, the efficiency drops and increases again at lower temperatures. When there is no irradiation at around 5 pm, the module efficiency remains at Standard Test Condition (STC), in this case 19%. These are the conditions under which the model is operating to give the stated results as discussed in the sections that follow.

In the current settings, the residential and industrial systems studied are not capable of avoiding the capacity reserve costs associated with the generation capacity. This is because they do not decrease the peak demand on the utility customer. Therefore the utility is less likely to reduce capacity requirements that can put less strain on transmission lines as indicated in the literature [22][23]. Only the commercial PV system shows some effects because of the presence of peak shaving benefits as shown in Table 11.

The annual average inverter efficiencies are 96% for residential and industrial PV systems, 98% for commercial PV system while annual average module efficiency for the solar modules used remains at 10%.

In Morocco, the annual average module efficiency of the assessed net metered PV system was 12.39%, which is slightly higher but not very far from the performance predicted for the systems under this study [16]. The difference is likely to be caused by variations in meteorological data of the two places. The annual average system efficiencies for residential, commercial and industrial net metered PV systems under study are 39%, 40% and 38% respectively with annual capacity factors of 19%, 20%, and 20% respectively. These figures are good compared to others in literature and they are positively indicative about technological viability of the PV system in Lesotho.

4.2 Energy Economics analysis

The simulation of net-metered solar PV systems for three customer types yielded the summarized results shown on Table 11. As pre-determined by the policy guidelines in Chapter 3.1, the total annual energy produced by the PV system is equivalent to the total annual load of the prosumer. The implementation of the system is able to shave the demand peak costs during the peak hour consumption for the commercial prosumer by $3,868.17 for 214.8 kWh per year. This is one the benefits that goes to the prosumer. The utility benefit will be on avoidance of the capacity reserves for this particular client.

Table 11: Generated results from the simulation of three customer categories

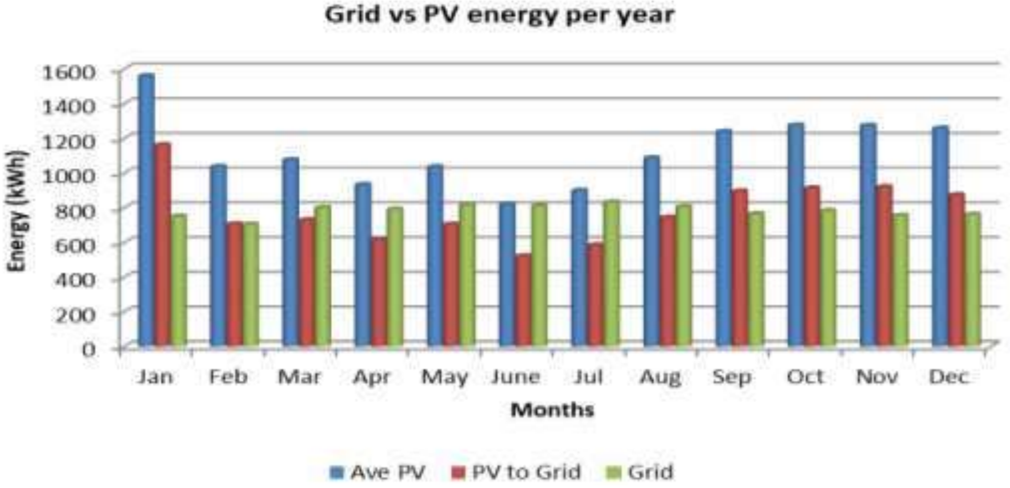
	Descriptions	**Residential**	**Commercial**	**Industrial**
	Daily load	37000	4462258.06	4462258.06
	Systems Capacity	8.0 kWp	944.1kWp	939.2kWp
	Annual energy	13499 kWh	1628.1MW	1628MW
	Capital cost **($)**	3,341.40	334,029.13	296,806.48
Prosumer	Annual Avoided Energy cost **($)**	409.64	12,814.40	9,335.61
	Annual Energy Sales **($)**	932.91	15,281.70	18,757.36
	Annual Peak Shaving benefits **($)**	-	3,868.17	-
	Annual Net benefits **($)**	1,342.55	31,964.26	28,092.97
	NPV **($)**	9,237.00	-566,076.28	-487,866
System				
	LCOE **($)**	0.0472	0.9760	0.9793
	Profitability index at 3% discount rate	2.7643	-1.6947	-1.6437
Utility	Avoided Costs ($)	344.85	62,174.29	45,295.54
	Energy sales ($)	94.65	1,982.18	2,046.33
	Current Revenue with PV($)	439.50	68,024.64	47,341.87
	Expected Revenue without PV ($)	1,342.58	94,140.36	71,115.72

From Figure 19, the PV systems for the three utility customers under study produce more energy in the summer season (November to January) and there is less production in the winter season especially during June and July. When there is more energy produced, less energy is demanded from the grid, and with less production from the PV system, more energy is demanded from the grid. The residential PV system sells more energy to the utility in terms of percentage as compared to other commercial and industrial PV systems.

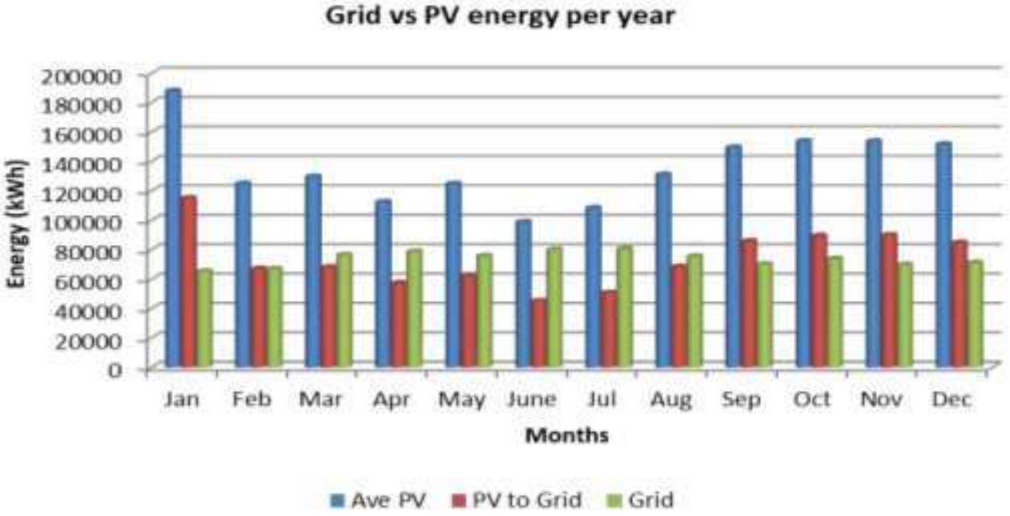
With reference to Figure 20, there are more net metering benefits for the residential clients especially during summer months (November, December and January). The system is able to generate more energy of which access is fed into the grid and most of the energy demand is met. On average, the net benefits of net metering is about one third (1/3) of the total costs of buying electricity from the grid when the PV system is not installed. This is opposite with commercial and industrial customers. The net benefits constitute about ten percent of the capital costs for each system.

The NPV and profitability indices for both of these systems are negative. These are further discussed in the next section.

a) Monthly energy production for residential 8.0 kWp Solar PV system



b) Monthly energy production for commercial 944.1kWp Solar PV system



c) Monthly energy production for Industrial 939.2KWp Solar PV system

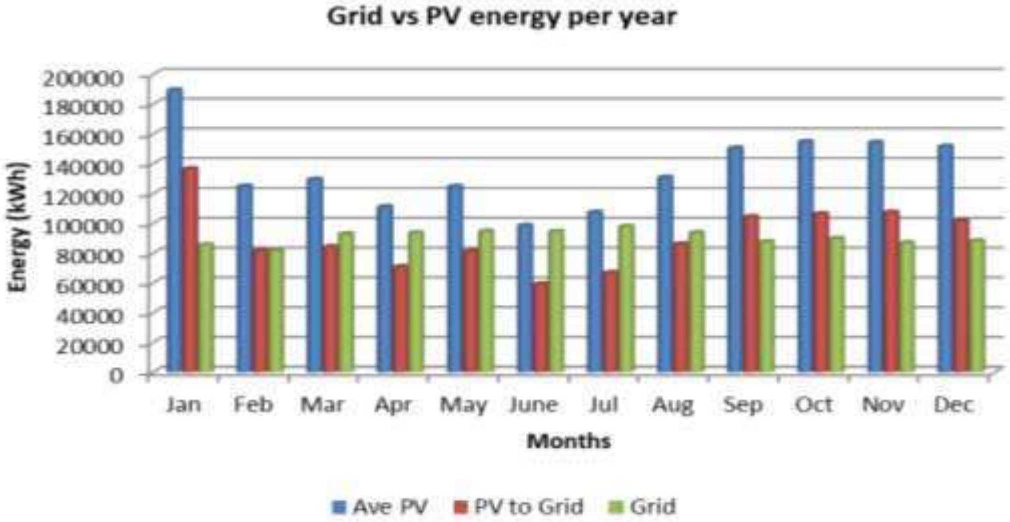
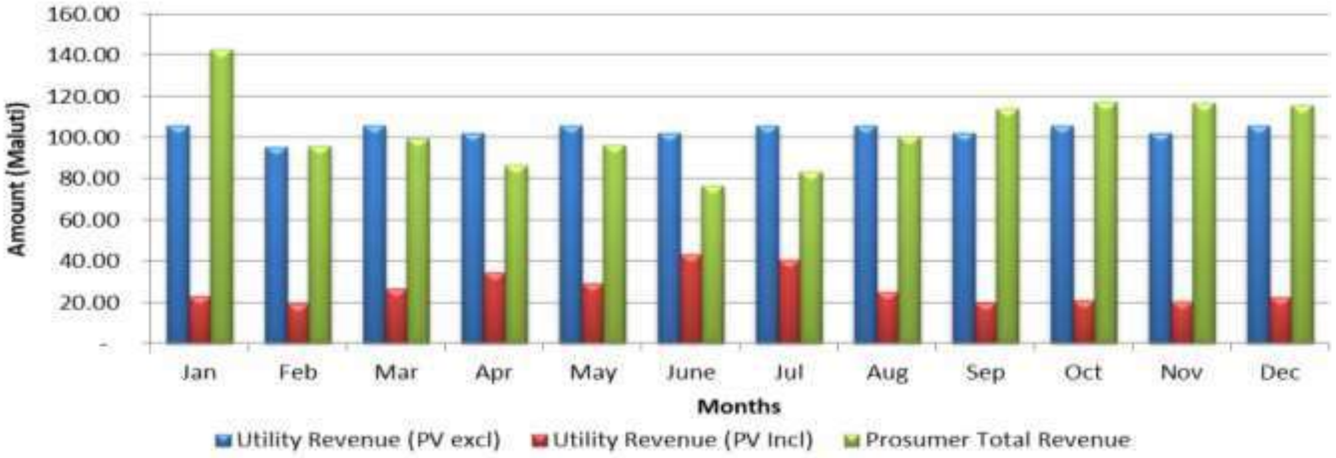


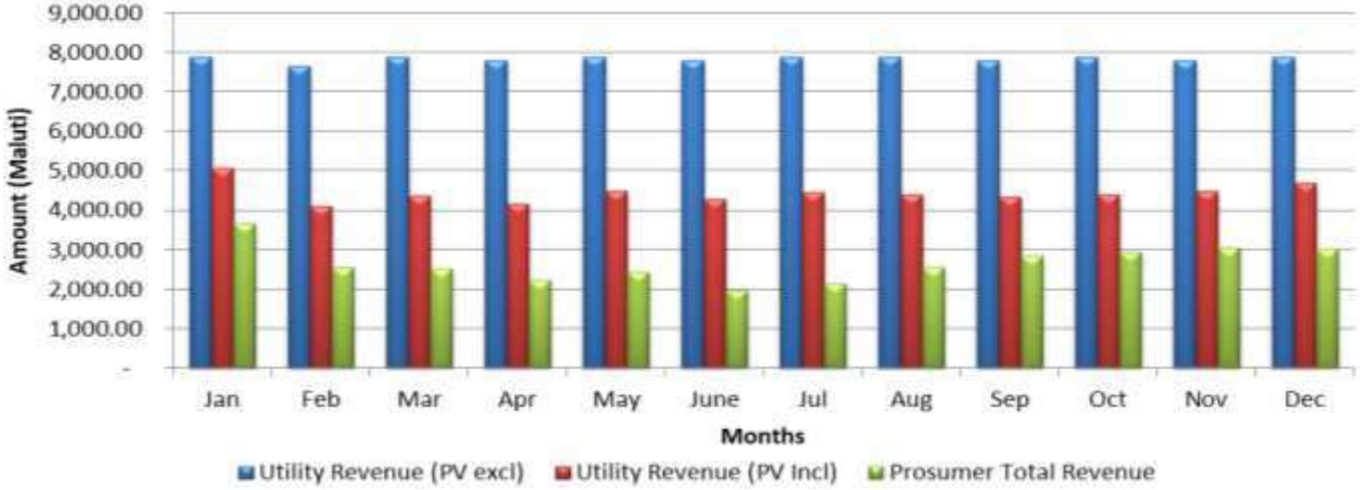
Figure 19: The monthly energy production for three customers

The monthly Revenues for Utility and Prosumer

b) **Residential 8.0 kWp Solar PV system**



b) Commercial 944.1 kWp Solar PV system



c) Industrial 939.2 kWp Solar PV system

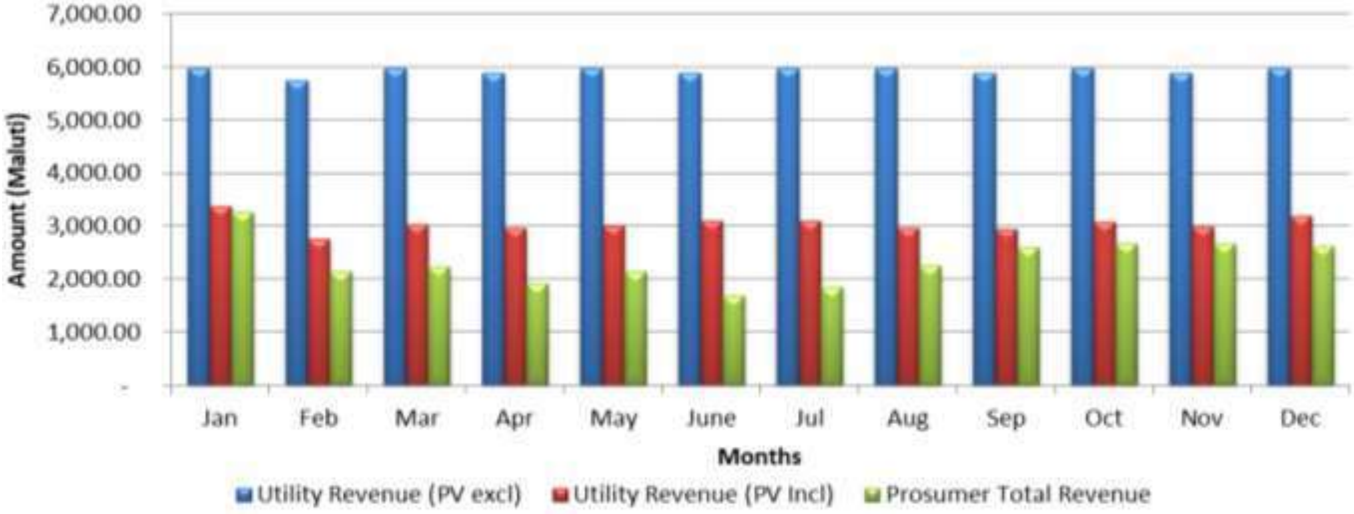


Figure 17: The monthly benefits for Utility and Prosumer

4.3 Current scenario

Table 12: Economic variables extracted from Table 11

Customer type	**System size**	**Capital costs ($)**	**Net metering benefits ($)/year**	**NPV**	**LCOE**	**PI**	**IRR**	**Payback**
Residential	8.0	3,341.40	1,342.55	9,237	$ 0.0472	2.7643	13	3
Commercial	944.1	334,029.13	31,964.26	-566,076	$ 0.9760	- 1.6947	-	-
Industrial	939.2	296,806.48	28,092.97	-487,866	$ 0.9793	- 1.6437	-	-

Based on Table 12, the cost of producing electricity (LCOE) for commercial and industrial PV systems is very high, which is about twenty one times (21) more than that of a residential PV system. Moreover, the two LCOEs are larger than the cost of buying electricity from the utility at the current retail price of $0.02 for high voltage customers. Therefore, the NPV values obtained are negative, which indicates that with the current load profiles and electricity prices for commercial and industrial customers, net metering is not viable. However, for the residential customers, the NPV value is positive hence net metering proves profitable with an IRR of 13% while the cost of producing energy is $0.0472 per kilowatt. Any discounted value from three percent (3%) to thirteen percent (13%) is acceptable for the project.

When the residential PV system results are compared with similar works done by Pacudan (2018) in Phillipines, the simulated 8kWp under this study has shorter payback period of three (3) years as compared to six (6) years and its IRR is 13% as compared to 19.2% . The profitability index for residential PV systems is 2.7643; this means that the benefits are one hundred and seventy-six percent (176%) more than the costs of the system. This is also higher than for the similar study done for Arizona Public Service by McGuire (2013) on residential market which only had profitability index of 1.54.

Since the retail price for residential customer for every kilowatt-hour is currently about six times larger than for commercial and industrial customers in Lesotho, the residential PV system is very attractive. Because of the huge gap between energy charges for these utility customers, there is a need to compare the local charges with other countries in the Southern Africa region. The comparison is shown in Table 11. The results show that Lesotho through LEC has comparatively low energy charges for its high voltage customers as compared with other regional countries. These low charges are not enabling factors for net metering systems for commercial and industrial high voltage customers. However, performing sensitivity analysis on the retail prices against the NPV gives hope as discussed in the section 4.4.1 below.

Table 13: Comparing Energy Charges for Lesotho with other Countries

(Charges have been averaged) [52]

Country	Category Description	Energy Charges ($)	Month
Botswana	Average Business	0.08425	April, 2018
	Large Business	0.05900	
Zimbabwe	Commercial/Industrial		October,2019
	11kV /33 kV average ToU	0.061	
South Africa	Industrial		July,2019
	High Season	0.140	
	Low Season	0.0830	
Lesotho	Industrial/Commercial		April,2020
	HV	0.0130	

Based on Table 13, presently the LCOE for commercial PV system is $ 0.9760 which is 75 times more than the energy charges of electricity in Lesotho and 7 times more than the energy charges in the neighboring country (South Africa). Koumparou et al (2017) has pointed out that the LCOE for the PV systems in many countries with good solar potential are lower or same as prices of electricity. Comparatively, Lesotho has high solar potential, but it shows the completely opposite scenario for commercial and industrial PV systems.

4.4 Sensitivity analysis

4.4.1 Increasing Electricity prices

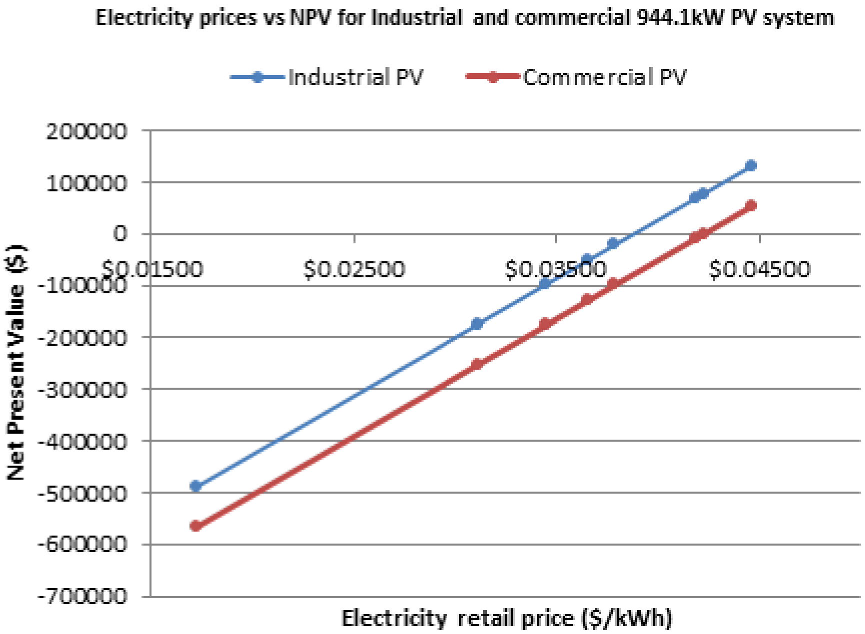


Figure 21: The sensitivity test for electricity retail prices against NPV

As shown on Figure 23, testing the sensitivity of the retail prices against the NPV for commercial PV system shows that the retail price that can give the positive NPV should be greater than $0.04227 per kilowatt-hour. Then for industrial PV system the electricity price should be greater than $0.03881 per kilowatt-hour in order to get a positive NPV. With reference to Table 14, at least if the retail price for both high voltage customers is $0.045, which is not different from what South Africa is charging for net metering of PV systems at Nelson Mandela Bay, then the industrial customers will benefit more from the net metered PV system. The profitability index is 44% as opposed to the 16% for commercial net metered PV system. The variation of profitability index between the commercial and industrial PV systems is caused by the difference in load profiles of each utility customer. Load shifting may have larger impact as discussed on section 4.4.2.

As literature shows, the concept of net metering is very sensitive to the electricity prices. Low prices can be negative stimulation for participation of PV power net metering systems. In this case increasing energy prices has positive effect as explained by Schelly et al (2017) [48].

Table 14: Results showing effect of proposed retail prices for commercial and industrial customers

Customer type	System size (kWp)	Proposed Retail price $/kWh	NPV ($)	LCOE	PI	IRR (%)	Payback period (Yrs)
Commercial	944.1	0.045	52,512	0.0022	0.1572	5.03	15
Industrial	939.2	0.045	130,653	0.0055	0.4402	7.88	11

The effect of using retail prices suggested for electricity as shown in Table 14 puts the levelized cost of producing electricity (LCOE) much lower compared to proposed prices. As long the LCOE is lower than the retail price for any energy system, it is profitable to implement such a system.

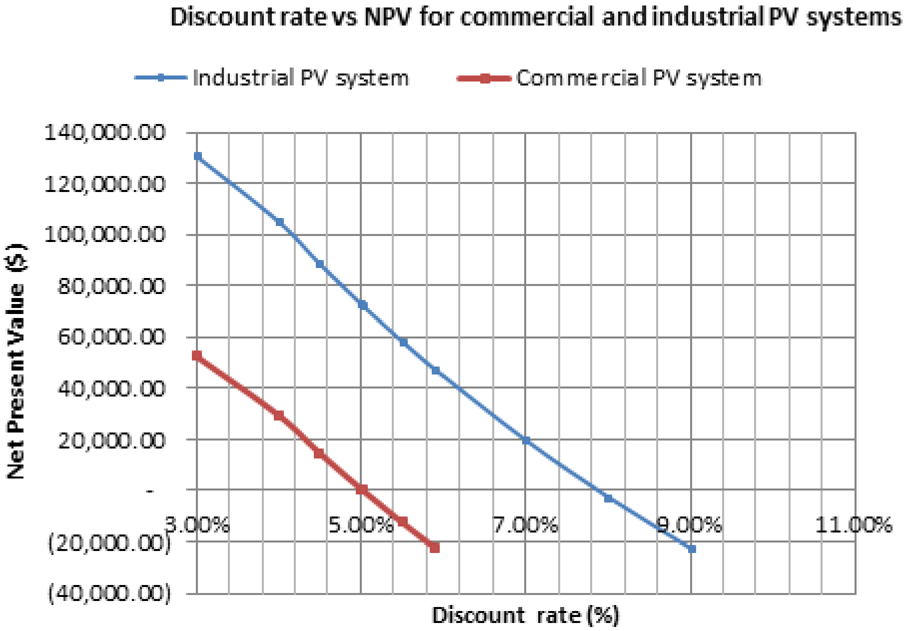


Figure 22: Showing discount rate at NPV=0

When the proposed retail price shown on Table 14 is used in the model and the increasing discount rate is plotted from three percent (3%) up to nine percent (9%) for both commercial and industrial PV systems, the results on Figure 22 are obtained. From this Figure, the discount rate that turns the NPV to zero (Internal Rate of Return or IRR) for commercial system is 5.03% while for industrial system is 7.88%. At this point the zero NPV means that implementing the system will eventually not yield any profits but it can work. The costs of implementing the system are equal to the benefits hence there is no net present value.

4.4.2 Changing the customer load profile by load shifting

Using the same daily load on commercial and industrial PV systems, the PV array sizes differ. However, the amount of energy injected and drawn from the grid differs for two customer categories hence the net metering benefits differ. Shifting the load demand to early hours using the same daily load on commercial PV systems yields different results. If the load is shifted backward by three hours, operations starting at 4 am will correspond with a maximum peak generation of PV power thus reducing peak demand even farther as shown in Figure 24. The PV array size increases to offer the required power (944.1kWp to 945.5kWp) while the peak power savings triples ($3,868.17 to $12,683.74).

Therefore the net impact of load shifting is that the benefits increase making the system more attractive to the implementers. Therefore the prosumer may decide on non-shiftable, power shiftable and time-shiftable appliances as to when to power them on or off (Hategekimana et al, 2017) [53]. In this case load profile shifting does not have an impact on generation-to-demand-ratio (GTDR) of the system, it still remains as one because at the end of the billing period, demand equals generation as outlined by the adopted policy.

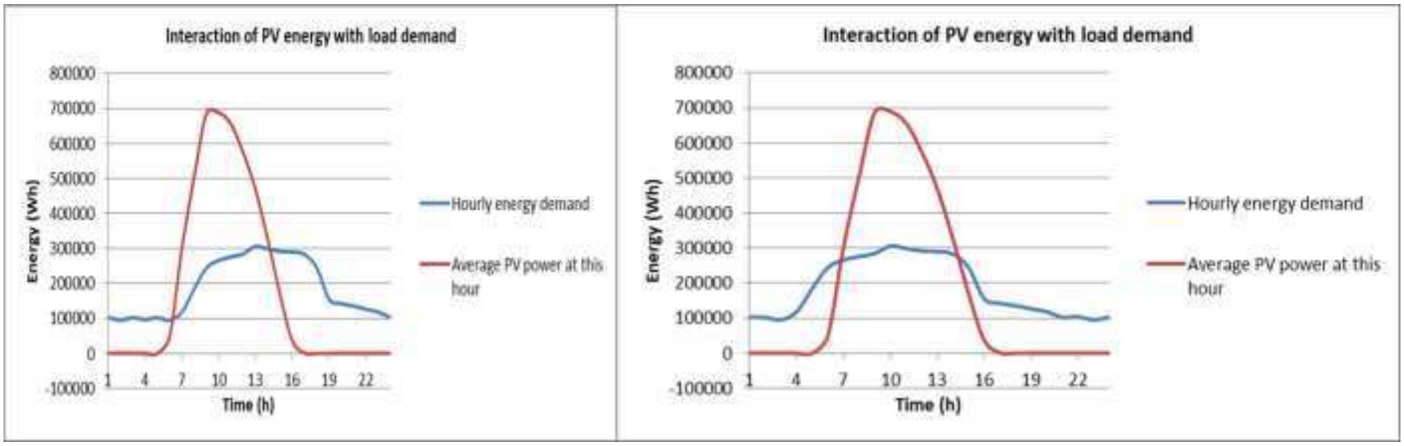


Figure 23: Interaction of PV energy with load demand when shifting load

4.5 Prosumer benefits Versus Utility benefits

The residential prosumer receives 31% of the total benefits which are generated from avoided costs of electricity and the remaining 69% is from the sales of energy to the utility. This agrees with the Beach and McGuire (2013) statement that PV is capable of reducing electricity demand [23]. From Figure 24 it is evident that this prosumer gets more benefits than the utility. This is because the peak power generation of

PV systems occurs during the off peak hours of prosumer's consumption. As a result, most of the energy is injected into the grid during these hours. This also means that the residential prosumer interacts more with the grid than other types of prosumers.

However, the opposite is true for the commercial and industrial prosumers. The utility still benefits more even when the PV system is installed. The prosumers will not be able to recover the system capital costs with the current tariffs, which is a discouraging factor for the system implementers. This is the case with different system capacities for each high voltage prosumer category.

The utility will not spend money to purchase 4119 kWh of energy annually for this customer if the 8 kWp PV system is installed and 453.09 kWh (11%) by system losses will be avoided. This agrees to what is stated by literature that grid connected solar PV system reduces transmission loses among others.

The avoided cost which now turns into utility savings makes $344.85 per annum and this makes 78% of the resultant income as indicated in Figure 24. These savings could be used for other developmental purposes. This also proves that the implementation of electricity net metering using PV systems is capable to reduce electricity imports if done on a larger scale [22].

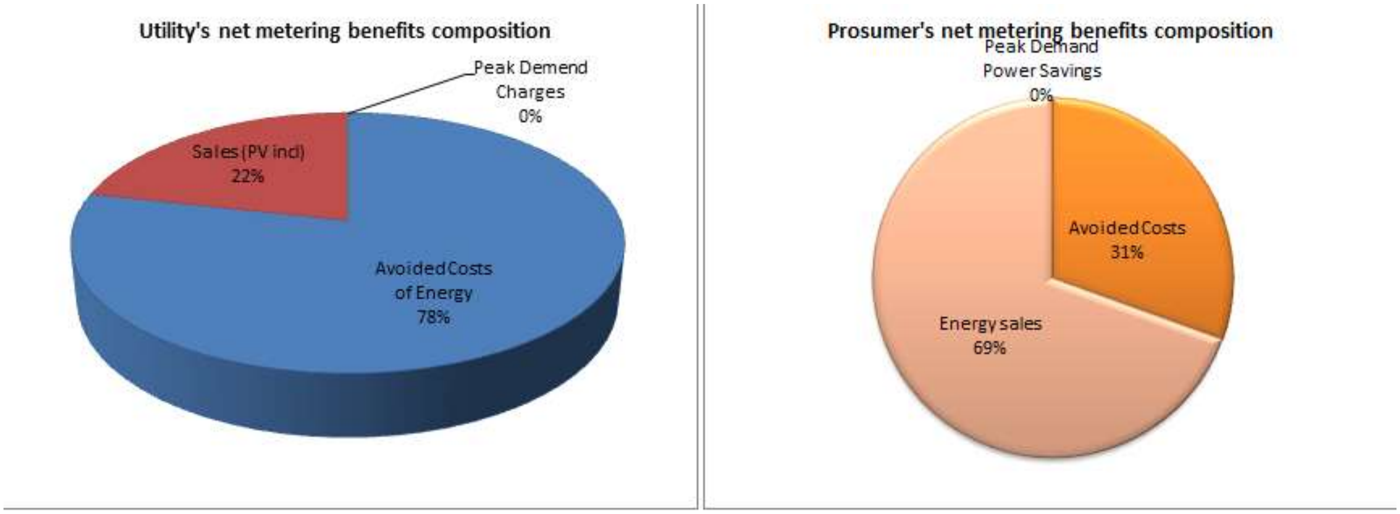


Figure 24: Percentage composition of the utility's and residential prosumer's net metering benefits

Chapter 5: Conclusion and recommendations

At least one variable from four categories suggested by Mejdalani et al (2018) of the sensitivity variables for net metering which been addressed for this study and are gaining interest are; (financial institution category), tariff level (regulator), inflation rate (exogenous), installed capacity (customer category).

a) When the installed capacity of the PV system gives the net electricity payments of zero at the end of the billing period, then the net-metered residential PV system offers the shorter payback period of three years which indicates quicker payment for borrowed capital investment. With the current tariff, the profitability index is 2.7643 at the discount rate of three percent (3%) which is very attractive for investment on the customer's perspective. The internal rate of return of the project is thirteen percent (13%) while the cost of producing energy is $0.0472 per kilowatt. Based on these results, it is concluded that with the current tariff settings for residential customers, PV net metering is technically and economically viable.

b) With the current electricity tariffs, the PV system that gives the net electricity payments of zero at the end of the billing period for commercial and industrial customers results in negative NPV values which indicate that the system is not acceptable. Therefore, the conclusion is that PV net metering for commercial and industrial activities is technologically viable but not economically. Otherwise, the energy retail prices greater than $0.0423 for commercial and $0.039 for industrial offers positive NPV values. The larger the retail price of electricity, the shorter the payback period of the PV system, which is likely to increase the utility customer's participation rate into the PV net metering systems.

c) Therefore, for PV electricity net metering to be a success, the Policy should address the current electricity prices for commercial and industrial customers. These customers pay less for energy yet they use more as compared to other customers.

Installations of net-metered residential PV systems will reduce Lesotho's electricity imports and transmission losses. At the same time it is more likely to increase the country's economy by introducing a new business model in the energy sector can that reduce unemployment amongst others.

The adoption rate of electricity net metering PV systems can be increased by allowing reasonable positive NPV values. The utility and the regulator should consider increasing the prices of buying electricity to values greater than $0.0423 per kilowatt-hour for commercial customers and $0.039 per kilowatt-hour for industrial customers. Since NPV also depends on the discount rate, the lower the discount rate, the better. However, the discount rate depends on inflation and interest rates. To attract more investment in this type of system, the interest rate of the investment should always be greater than the inflation rate. The larger the range between the two, the more attractive the investment can be.

The introduction of the time-of-use tariff which is higher than the retail price on the current tariff system may encourage the prosumers to shift their load demands profile to suit the solar PV system energy generation profile. This can make the system to be more useful to shave the peak demand yielding better results for the prosumer.

More studies on the utility’s costs analysis should be contacted so as to get full benefits from utility’s perspective on PV electricity net metering systems.

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