Assessment of Cost-Benefit for a Net Metering Scheme based on Solar PV: Case Study on a University Campus located in Lima-Peru.

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***Abstract*– A net metering scheme based on a 3.25-kWp Photovoltaic System was setup within the facilities of a university campus located in Lima-Peru for evaluation purposes. Solar PV system output as well as energy demand were registered for the entire year 2019. The contribution of solar PV production to total electricity demand is analyzed, considering seasonal variations in both the PV production and the energy consumption within the period of one year.**

Total implementation cost was calculated by adding CAPEX and OPEX values for a 3.25-kWp solar PV system operating under local conditions. In this case, total investment cost for the PV systems is estimated as 4,063 US$ while annual O&M costs are estimated as 71 US$.

Considering a local electricity tariff of 0.15 US$/kWh for the end user, annual cost savings is 1068 US/yr and the overall simple payback turns out to be 4.3 years. Therefore, it can be expected that potential introduction of a net metering squeme may become attractive for end users under local market conditions.

Keywords—Educational Facility, Energy Demand, PV Electricity, Cost-Benefit analysis, Environmental Management.

I. INTRODUCTION

Net metering based on solar on-grid PV systems at small scale is getting increased attention worldwide. In Peru, such squeme has not yet been implemented but expectations are high. In October 2015, Law Decree Nr 1221 stated an official definition for Distributed Generation; however, regulations for its commercial introduction are still in progress.

A small scale on-grid solar PV system was installed in the National Agrarian University La Molina (UNALM) located in Lima, Peru. Using its embedded monitoring system, solar PV energy production, as well as energy demand in one of the buildings, has been monitored all year long.

The research group is interested here in finding out how a solar PV system, connected to the grid, would perform under local weather conditions in a potential net metering squeme. And, how beneficial it might be for an end user under local current electricity tariffs.

II. BACKGROUND

In Ref. [1], in this study, several alternative policy options were assessed on the financial case for private homeowners investing in a PV system (simple payback time), on purchasing behavior (using a technology adoption model), and on governmental costs. While continuation of net metering policy leads to ongoing improvement of the financial case up to levels that could be considered overstimulation, three policy alternatives can be set up so that they stabilize simple payback times of recent and future generations of PV systems. Under these alternative instruments, deployment of PV systems in this market segment is indicatively estimated to be 15–20% lower by the year 2030 than with continuation of net metering policy, while corresponding governmental cost reduction indications would be more than 50%.

In Ref. [2], the policy of net metering allows operators of residential- and commercial solar PV systems to sell surplus electricity back to their utility at the going retail rate. This policy has recently been criticized on the grounds that it provides a subsidy for residential and commercial solar installations, a subsidy that is paid for by all ratepayers. In response, public utility commissions have begun to take up this regulatory issue.

In Ref. [3], the present work examines the impact on consumer electricity bills under five different cases based on different compensation mechanisms to evaluate PV generation units for 120 residential consumers, for assessing the pertinence of energy policy to be introduced for encouraging rooftop PV in India. The consumers are categorized based on their lifestyles. It is found that lower the size of the panel, lower is the savings leading to a decrease in the attractiveness of a rooftop PV system for a residential consumer. Also, the compensation mechanism and injection tariff play a crucial role in making a rooftop PV system feasible for a residential consumer. It is observed that the achieved savings of a consumer is a function of compensation mechanism and seasonal load pattern of a consumer.

In Ref. [4], with the continued growth of distributed power generation, the number of customers who consume and produce energy via solar photovoltaic (PV) power generation (solar prosumers) has been increasing. Unfortunately, electric utilities are not aware of the location of all solar prosumers due to unauthorized or unreported installations and lack of separate PV metering in areas with Net Energy Metering policies. Knowledge of the location of solar prosumers can inform circuit protection and voltage regulation settings, and help grid operators improve situational awareness and better plan for daily variations in demand, which are further magnified by generation intermittency.

In Ref. [5], as the cost of solar photovoltaic (PV) systems decreases and incentives such as feed-in tariffs (FiTs) are offered, solar-PV homes are becoming popular. Furthermore, solar-PV homes integrated with hybrid or electric vehicles (EVs)

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are emerging as a paradigm for future homes. Given the fact that there exists a considerable price difference between grid electricity supply and FiTs, decision making of energy storage using batteries becomes an imperative topic.

In Ref. [6], it is investigated the impact of retail rate design on the investment incentives, avoided utility costs, and cost-shifting concerns associated with rooftop solar plus battery storage systems that are located behind-the-meter. To illustrate these interactions, the authors consider recently proposed changes time-of-use pricing policy for commercial and industrial consumers which shifts on-peak prices from midday to the constrained evening hours. It is found that these rate adjustments reduce cost-shifting concerns across consumers considerably, but also decreases solar PV investment and has an ambiguous effect on storage investment.

In Ref. [7], in a climate of soaring energy prices not all consumers are able to afford the upfront investment costs in photovoltaics to manage their energy costs. Virtual Net Metering enables the sharing of generation and storage benefits against the load of decentralized customers including apartments. The aggregation of resources can reduce the cost for monitoring and managing distributed generation. This is possible by the use of innovative technology for monitoring, billing and settlement software.

In Ref. [8], significant growth of behind-the-meter solar Photovoltaic (PV) power generation in recent years is changing the shape of the net demand for electricity from electrical grids. In this work, a framework is proposed to forecast the aggregated power generation of a large fleet of small behind-the-meter solar PV sites. The outputs of those sites are not individually measured and thus, the aggregated output is "invisible" to power system operators.

In Ref. [9], this study addresses the terms, conditions and effectiveness of policies reflected as the inter-annual growth in PV power production with respect to the potential realizable capacity in the country. Additionally, a life cycle cost and greenhouse gas (GHG) emission reduction analysis is presented to demonstrate the economic viability and environmental impact of implementing an on-grid residential PV installation in the country.

III. Electricity Market in Peru

A. *Electricity generation mix*

The electricity sector of Peru is composed by generation, transmission, distribution, and end-users, as it is normally elsewhere.

According to last official reports, as from 2018, electricity was produced mainly by: thermal power plants (37.82%), hydropower plants (57.77%), solar power plants (1.47%), and wind power plants (2.94%).

It is important to mention that, in Peru, natural gas became a major player in the generation mix as from 2004. Before that, the country use to generate electricity by using centralized hydropower plants.

Also, renewable energy, including solar, wind, and others, started to enter into the electricity market in2010.

Table I shows electric power generation registered in 2018.

TABLE I

Electric Power Generation by Type in 2018		
Type	**Energy (GWh)**	**Participation (%)**
Hydropower	29,357.9	57.77
Thermal	19,220.0	37.82
Solar	745.2	1.47
Wind	1,493.6	2.94
Total	**50,816.8**	**100**

Source: Operations Statistics 2018 COES

Thermal power plants are run on different fossil fuels depending on the technology involved. It is important to mention that, in Peru, most of the electricity produced by thermal power plants comes from combined cycle units that run on natural gas.

Table II shows thermal power production by technology in 2018.

TABLE II

Thermal Power Production by Technology in 2018		
Type	**Energy (GWh)**	**Participation (%)**
Combined Cycle	16,550.4	86.11
Gas Turbine	2,299.5	11.96
Steam Turbine	161.6	0.84
Diesel Engine	208.5	1.09
Total	**19,220.0**	**100**

Source: Operation Statistics in 2018 COES

The following figure highlights the major role played nowadays by combined cycle technologies in the electricity mix of Peru.

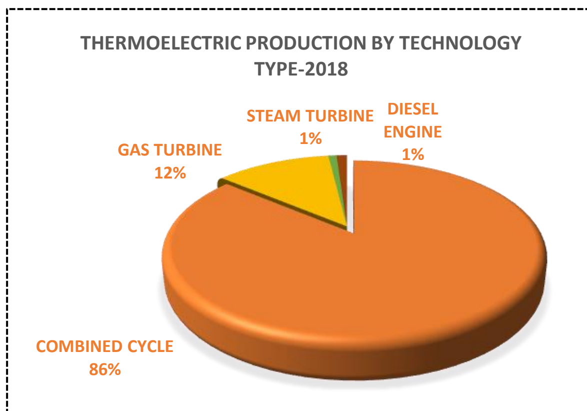

Fig. 1: Thermal Power Production by Technology in 2018

Energy demand has been increasing in the last decade at a moderate pace. Maximum demand was registered on December 17, 2018 at 19h45. Table III, shows electricity generation used during peak demand.

TABLE III

Maximum Demand by Technology Type (Dec. 18, 2018 at 19h45)	
TECHNOLOGY TYPE	TOTAL (MW)
Hydroelectric	3,972.2
Wind	247.1
Combined cycle	2,474.2
Gas turbine	116.3
Steam turbine	47.3
Diesel Engine	27.5
Total	**6,884.6**

Source: Operation Statistics in 2018 COES

Minimum power was registered in January and accounted for 4,025 MW. Maximum power was registered in December and accounted for 6,928 MW. Maximum power during pick hours were registered in December and accounted for 6,885 MW. Total annual energy production reached 50,817 GWh with an overall average load factor of 0.837. Table IV shows monthly power demand, energy production and load factor for the year 2018.

TABLE IV

Load Factor in 2018					
Month	**Min Power (MW)**	**Max Power (MW)**	**Max Power During Pick Hours (MW)**	**Energy Production (GWh)**	**Load Factor**
Jan	4025	6592	6489	4255.25	0.868
Feb	4582	6719	6577	3919.54	0.868
Mar	4546	6670	6640	4315.87	0.870
Apr	4603	6711	6711	4207.90	0.871
May	4501	6617	6617	4287.98	0.871
Jun	4518	6542	6542	4134.92	0.878
Jul	4286	6443	6463	4200.01	0.876
Aug	4557	6519	6519	4221.87	0.870
Sep	4614	6554	6554	4143.36	0.878
Oct	4622	6658	6658	4354.59	0.879
Nov	4795	6786	6786	4279.41	0.876
Dec	4304	6928	6885	4496.08	0.872
Total	**4,025**	**6,928**	**6,885**	**50,816.79**	**0.837**

B. End-use electricity consumption

According to last official reports, 2017, electricity was consumed mainly by: residential (21%), commercial (17%), industrial (25%), and mining (32%) sectors. All together, they represent approximately 91% of total electricity consumption in the country.

The following figure shows electricity consumed by different sectors in the year 2017.

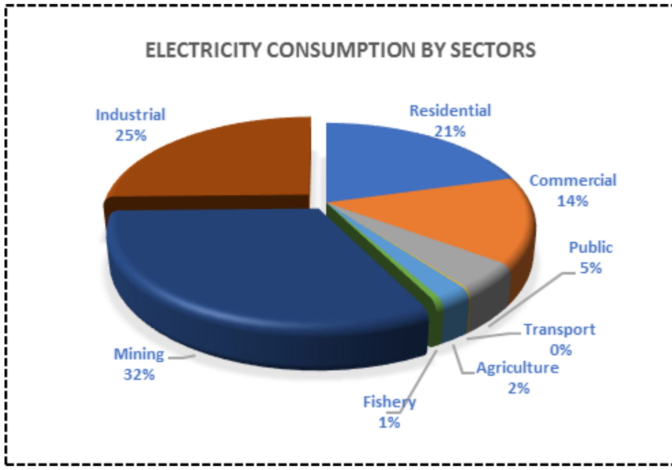

Fig. 2: Electricity consumption by sectors in 2017
Source: National Energy Balance 2017 MINEM

Most of the energy was consumed by the mining sector followed by the industrial and residential sector. Table IV shows electricity consumption by each sector in 2017.

TABLE IV

Electricity Consumption by sectors in 2017	
Sector	Consumption (GWh)
Residential	9573.4
Commercial	6741.1
Public	2106.6
Transportation	53.1
Agriculture	1015.9
Fishery	258.5
Mining	14946.3
Industrial	11769.9
Total	**46464.8**

Source: National Energy Balance 2017-MINEM

IV. PV ELECTRICITY PRODUCTION

A. Solar PV System

A 3.25-kWp solar PV system, installed on a university campus located in the city of Lima, was considered for evaluation purposes. The solar PV system, contains PV modules, inverters, controllers, and a monitor. The following figure shows the solar PV system considered for this work.

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Fig. 3. A 3.25-kWp Solar PV System
Source: Sunny Portal Web

Table V shows technical specification for the PV Module. Model Module: Canadian Solar Inc. CS6U-325P.

TABLE V

Mechanical Data	
Specifications	**Data**
Cell Type	Poly-crystalline, 6inch
Cell Arrangement	72 (6x12)
Dimensions	1960x992x40 mm (77.2x39.1*1.57 in)
Weight	22.4Kg (49.4lbs)
Front cover	3.2mm tempered glass
Frame material	Anodized aluminum alloy
J-Box	IP67,3diodes
Cable	4mm2 (IEC)OR 4 MM2 &12AWG 1000V (UL),1160mm (45.7in)
Connector	T4series or PV2 series
Per Pallet	26 pieces, 635 Kg (1400lbs)
Per container (40'HQ)	624 pieces

Table VI shows technical specifications for the Inverter. Model Inverter: Sunny Tripower 5000TL-20. Monitor is Sunny Home Manager 2.0.

TABLE VI

Technical Data	
Input (DC)	**Sunny Tripower 5000TL**
Cell Type	9000Wp
Cell Arrangement	1000V
Dimensions	245V to 800V/580V
Weight	150V/188V
Front cover	11A/10A
Frame material	17A/15A
J-Box	IP2/A:2; B:2
Output (AC)	
Rated power (at 230V,50Hz)	5000W
Max. AC apparent power	5000VA
Nominal AC voltage	3/N/PE;230/400V
AC grid frequency/range	50Hz/+-5Hz
Rated power frequency/rated grid voltage	50Hz/230V
Max,output current	7.3A
Power factor at rated power	1
Adjustable displacement power factor	0.8 overexcited to 0.8 underexcited
Feed in phases/connection phases	3/3
Max efficiency/European efficiency	98%/97.1%

B. *Data Collected*

Data for 2019 was downloaded from a virtual platform. Information about solar photovoltaic production and electric grid consumption is recorded every 15 minutes during 24 hours per day and 365 days per year.

The average power was registered each 15 minutes during each month; however, during Jan. 22-23, Mar. 8, April 23-25, and May 9-14, data was not recorded properly.

Solar photovoltaic production (kWh) was calculated for every 15 minutes, based on the average power demand. Finally, total monthly energy production is obtained for the year 2019.

C. *PV Electricity Production*

The PV electricity production has been changing along the year. The maximum production was registered in March and the minimum in July. Table VII shows monthly solar PV production in kWh.

TABLE VII

Month	PV Production (kWh/day)
January	14.3215
February	14.8828
March	16.3533
April	15.0536
May	7.2395
June	5.1556
July	5.0351
August	8.0960
September	10.6789
October	13.4840
November	13.5656
December	12.5280

The following figure shows hourly solar PV production for an average day in March. Solar PV production starts about 06h15 and stops about 18h15.

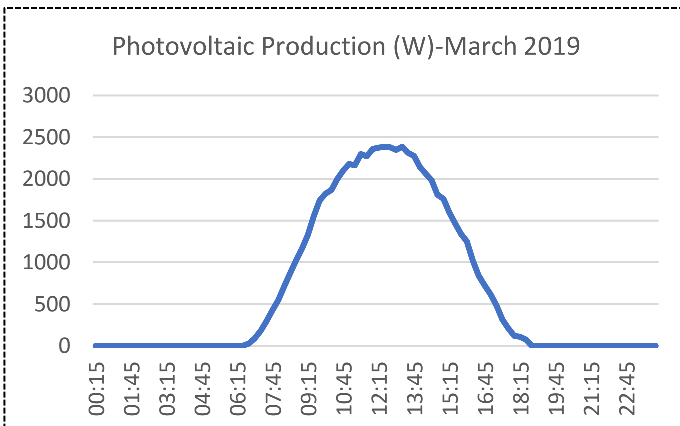

Fig. 5: Average Photovoltaic Production (W) in March 2019
Source: Own elaboration

The following figure shows hourly solar PV production for an average day in July. Solar PV production starts about 06h45 and stops about 17h45.

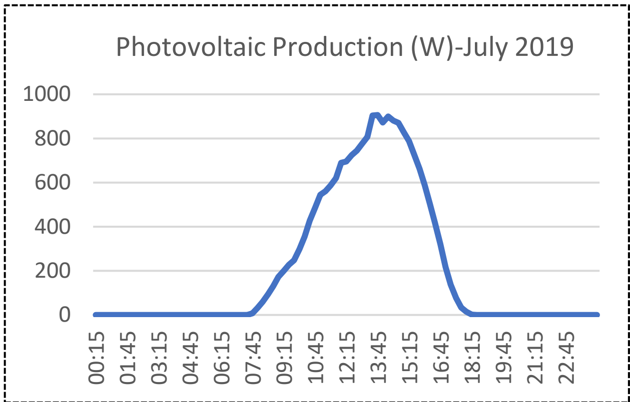

Fig. 6: Average Photovoltaic Production (W) July 2019
Source: Own elaboration

V. ENERGY CONSUMPTION

A. *Data Collected*

Data for 2019 was downloaded from a virtual platform. Information about solar photovoltaic production and electric grid consumption is recorded every 15 minutes during 24 hours per day and 365 days per year.

The average power was registered each 15 minutes during each month; however, during Jan. 22-23, Mar. 8, April 23-25, and May 9-14, data was not recorded properly.

Energy consumption (kWh) was determined for every 15 minutes, based on the average power demand. Finally, total monthly energy consumption is obtained for the year 2019.

B. *Energy Consumption*

Energy consumption has been changing along the year, the maximum energy consumption was in May and the minimum in August. Table VIII shows monthly energy consumption.

TABLE VIII

Month	Energy Consumption (kWh/day)
January	20.9893
February	21.2235
March	22.8454
April	22.1991
May	23.2051
June	18.8904
July	16.4733
August	16.3154
September	18.7167
October	21.4957
November	21.6752
December	20.4894

The following figure shows hourly energy consumption for an average day in May. Maximum power demand occurs at about noon. In Lima, during May mild temperatures are registered (autumn).

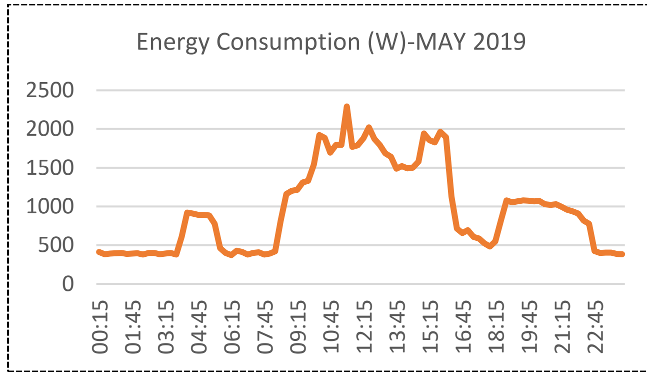

Fig. 7: Energy Consumption (W) in May 2019
Source: Own elaboration

The following figure shows hourly energy consumption for an average day in August. Maximum power demand occurs also at about noon. In Lima, during August lower temperatures are registered (winter).

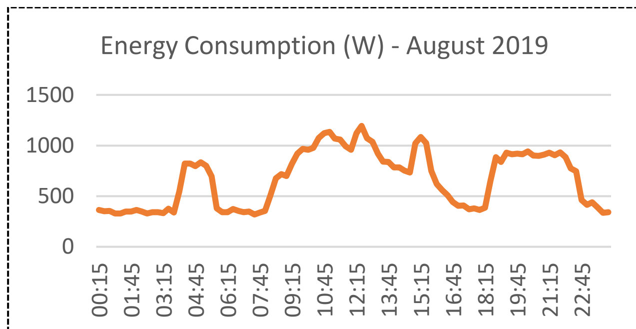

Fig. 8: Consumption (W)-August 2019
Source: Own elaboration

C. *Energy Savings*

To sum up, Table IX shows monthly energy savings.

TABLE IX

Month	PV Production (kWh)	Energy Consumption (kWh)	Energy Savings (kWh)
January	14.3215	20.9893	-6.6678
February	14.8828	21.2235	-6.3406
March	16.3533	22.8454	-6.4921
April	15.0536	22.1991	-7.1455
May	7.2395	23.2051	-15.9657
June	5.4048	18.8904	-13.4856
July	5.0351	16.4733	-11.4382
August	8.0960	16.3154	-8.2194
September	10.6789	18.7167	-8.0378
October	13.4840	21.4957	-8.0117
November	13.5656	21.6752	-8.1096
December	12.5280	20.4894	-7.9614

VI. Cost Savings and Payback

Capital investment cost for implementation of an on-grid PV system depends on installed capacity among other things. CAPEX unit cost for a 3.25-kWp can be estimated as 1,250 US$/kWp.

Annual operation and maintenance costs for an on-grid PV System depends on complexity of the system and distance to reach the on-site installation, among other things. For a system located in the city of Lima and with the technical characteristics described above, OPEX unit cost can be estimated as 0.01 US$/kWh.

LCOE, the Levelized Cost Of Energy, takes into account both CAPEX and OPEX during the entire project life. Replacement of components (controllers, inverters, and the kind) is also included in the capital investment cost.

In this case, project life will be considered as 20 years. Local financial institutions usually consider an annual discount rate of 12% for energy projects. Considering such discount rate and project horizon, an annuity factor (P/A) equal to 7.469 is obtained.

Then, total CAPEX cost is 4,063 US$. Considering a solar PV production of 7,118 kWh/yr, OPEX cost turns out be 71 US$/yr, and using the above annuity factor, it becomes 532 US$. Total cost for the solar PV system is therefore 4,594 US$.

Total energy to be produced by the solar PV system, in 20 years, is 142,350 kWh. The LCOE value in this case is 0.032 US$/kWh. Local end-user electricity tariff is about 0.15 US$/kWh, which is higher than the LCOE value found in this case.

So, the end user invests a total of 4,594 US and achieves a cost savings of 1,068 US$/yr. Therefore, overall simple payback is 4.3 years.

VII. Conclusions

PV electricity production varies as a function of solar irradiation throughout the entire year. The highest monthly electricity production reached 16.35 kWh/day and was registered in March. On the other hand, the lowest monthly electricity production reached 5.03 kWh/day and was registered in July.

Energy consumption also varies as a function of campus activities throughout the entire year. The highest monthly energy consumption accounted for 23.20 kWh/day and was registered in May. On the other hand, the lowest monthly energy consumption accounted for 16.31 kWh/day and was registered in August.

In terms of investment cost for the PV System, 4,063 US$ was considered as CAPEX while 71 US$/yr was considered as OPEX. Thus, considering a discount rate of 12% and a project life of 20 yr, LCOE is determined as 0.032 US$/kWh.

Energy savings associated with solar PV generation for the entire year 2019 was 7,118 kWh. Considering an end-user electricity tariff of $0.15/kWh, total annual cost savings represents 1,068 US$/yr. Therefore, considering a total implementation cost of 4,594 US$, an overall payback period of 4.3 years is obtained.

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