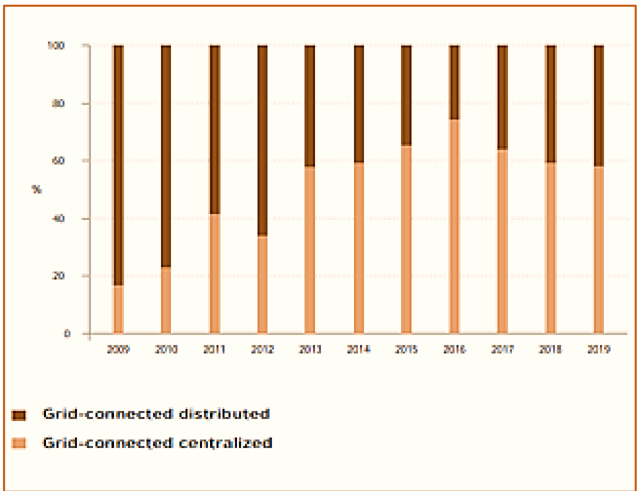
Techno-economic Analysis of Net-metered Solar Photovoltaic Systems for Residential Households in Pakistan

Issue Brief

1. Introduction

Solar photovoltaic electricity is becoming the cheapest source of power procurement in many countries worldwide. It reached nearly 6232 GW of cumulative PV applications by the end of 2019, while another 107 GW of additions were made in 2020 alone.[1] Although utility-scale PV systems have been driving most of this growth, recently net-metered and grid-tied prosumage has become largely popular in many countries. This is due to attractive tariff designs, strong synergies rooted in high cost of conventional energy, unreliable power supply and inter-linked strong demand by end-users, especially in global south, and overall its favorable economics.

Figure 1: Annual Share of Centralized and Distributed Grid-Connected Installations Globally 2009-2019



Source: IEA PVPS (2020)

Geographically positioned in an ideal solar zone, Pakistan has also been ambitiously seeking to promote renewable energy sources into its generation mix. To tap the enormous renewable energy potential, among other initiatives the government introduced net-metering regulations in 2015.

With these regulations, grid-tied prosumers could now both reduce the amount of electricity consumption from grid and net-off surplus units to their respective DISCO's at off-peak retail tariff.

However, it is important to note here that overall economic efficiency of net-metered solar PV systems varies from region to region, affected by multiple variables such as solar irradiances, atmospheric conditions, PV panels and inverter's specifications, etc. The techno-economic analysis of net-metered systems in Pakistan is a largely overlooked area in existing literature. This brief hence has been prepared to demonstrate detailed assessment of net-metered solar PV system in terms of its installation costs, generation cost, technical productivity, life-cycle analysis, pay-back period and return on investment. For the analysis, three system sizes i.e. 5 kW, 10 kW and 15 kW were selected from the residential sector of IESCO. Before delving into the analysis, we also present a quick overview of net-metering status and broader landscape in Pakistan. Finally based on the analysis showcasing significant favorable economics of net-metered solar PV in Pakistan, we propose some recommendations on actively encouraging grid-tied solar prosumage.

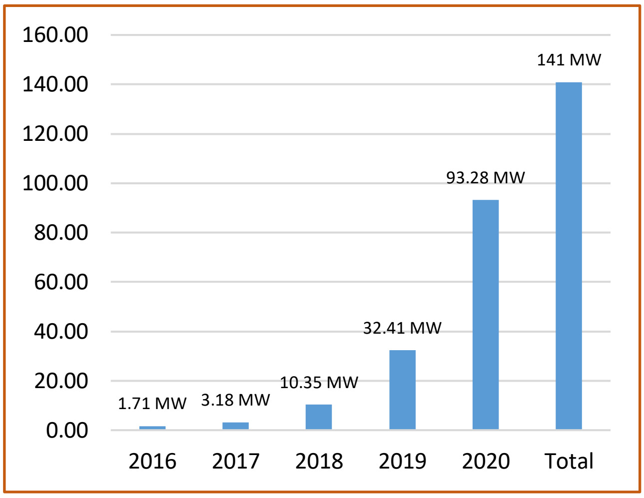
2. Net-Metering Status in Pakistan and Primary Driver of Prosumage

By the end of December 2020, net-metered connections in Pakistan reached cumulative capacity of 141 MW and 8,006 systems. The larger share of the

[1] IEA (2020), *Renewables 2020*, https://www.iea.org/reports/renewables-2020

installed PV systems is concentrated in the household sectors and urban centers of the cities. **Figure 2** shows the growth of net-metering installations (in MW) during 2016 to 2020.

Figure 2: Growth of Net-Metered PV Systems from 2016-2020.

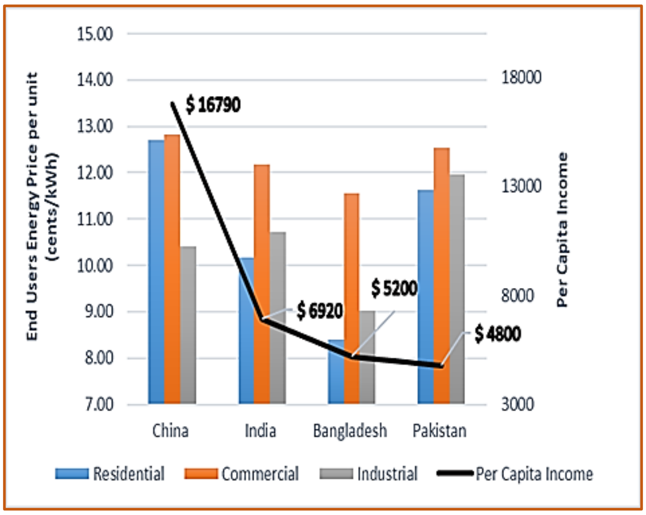


Source: IPS (2020)

Among other variables, high end-user retail tariff is most significant driver of prosumage. Following this insight, end-user retail tariff in Pakistan is highest compared to the broader region. For instance, China[2] has retail electricity tariff ranging between 10.4 cents/kWh and 12.71 cents/kWh; in the case of India[3] it lies between 10.1 cents/kWh and 12 cents/kWh, Bangladesh[4] has 8.4 cents/kWh to 11.6 cents/kWh, while Pakistan's[5] retail tariff ranges between 11.6 cents/kWh and 12.5 cents/kWh. Also, if we take into account the per capita income, the situation is further exacerbated for Pakistani consumers as the country has the lowest per capita annual income, making it overall less affordable for a large section of society. **Figure 3** shows the comparative analysis average retail tariff for residential, commercial and industrial consumers in China, India, Bangladesh and Pakistan.

Owing to the high electricity prices, the prosumage drive in Pakistan has overall been sluggish and uneven across different regions. Although more research is needed to look into multi-dimensional aspects of this slow net-metering uptake, this brief focuses only on analyzing the technical and economic feasibility for utilizing net-metered solar PV systems in Pakistan.

Figure 3: Comparison of End-User Retail Tariff and Per Capita Income of China, India, Bangladesh and Pakistan.



3. Methodology

This study analyses economic and technical viability of net-metered solar PV systems in the household sector. The analysis has been carried out for three different system sizes i.e. 5 kW, 10 kW and 15 kW grid-connected solar PV systems. Islamabad was chosen as case study region for carrying out the analysis.

A sample size of 20 households based in IESCO (who were relying on net-metered solar PV) was taken for each system category. From this sample size, the system specifications were extracted which included electricity consumption pattern and cost of PV panels and interlinked appliances. Further, the price quotations of the systems in consideration were also verified from solar vendors. Finally, PVSYST has been applied which is one of the widely used software used for technical evaluation and economic assessment of solar systems. We also used the software for carrying out this analysis.

a. Technical Assessment

PVSYST software defines the technology specifications to the simulator. This includes variables such as number of arrays, number of strings, array voltages and current, string voltages and currents, inverter specifications and operation modes. Based on these system specifications, the software tool

[2] "Electricity Markets and systems in the EU and China," June 2020, https://ec.europa.eu/energy/sites/default/files/electricity_markets_report_en.pdf
[3] Average retail tariff has been taken from the state electricity commissions of India.
[4] Source: Bangladesh Electricity Regulatory Commission (BERC)
[5] Source: National Electric Power Regulatory Authority (NEPRA)

optimizes and simulates the output of the system based on the geographical locality, performance ratio and module efficiency. **Table 1** illustrates the system configuration used for the simulation of PV systems.

Table 1: Technical Specifications for PV system

System Size	PV Panel		Inverter	
	Panel Make and Technical Specifications	No. of Units	Inverter Specifications	No. of Units
5 kW	Talesun Solar Modules, 295 Wp, Si-poly, TP672P-295	Modules in Series =17 No. of Strings = 1	Samil Power, 5.5 kW, 5500TL-PM	1
10 kW	JinkoSolar PV Modules, 440 Wp, Si-poly, JKM-200PP48	Modules in Series =12 No. of Strings = 2	AOTAI,12 kW, A-12000TL	1
15 kW	Longi Solar PV Modules, 400 Wp, Si-mono, LR6-72 HPH 400M	Modules in Series =19 No. of Strings = 2	Trannergy, 17 kW, TRN017KTL	1

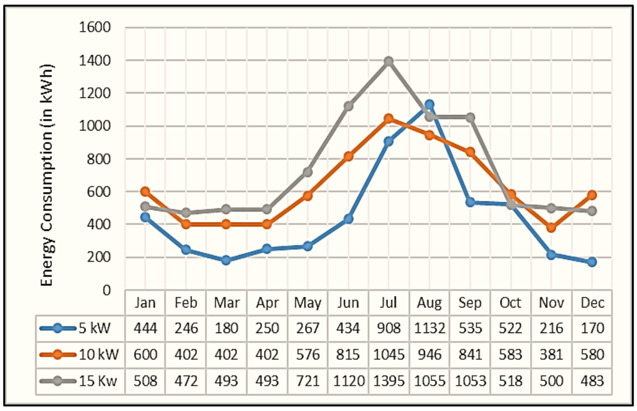
b. Economic Evaluation

In order to perform economic evaluation. PVSYST performs the function based on the resultant of output power with respect to optimized hours of operation in an annum. The economic terms such as payback period, return on investment and generation costs can be determined for the systems.

4. Results of Techno-economic Assessment

The values of aggregated energy consumption pattern for all three system sizes 5 kW, 10 kW and 15 kW— can be seen in **Figure 4**.

Figure 4: Aggregated Energy Consumption Profile for household residential customers with 5 kW, 10 kW and 15 kW sanctioned load.



With the installation of grid-tied net-metered system against the sanctioned load, the prosumers can reduce their electricity consumption from grid. Based on the system specifications, the total annual energy yield has been optimized and calculated (see **Table 2)**. Following assumptions have been made for the simulation:

- The sanctioned load of the prosumer and installed PV system capacity is same.
- No shading is considered.
- Soiling and mismatch losses are neglected.
- Global degradation factor for PV panels are considered to be 9.8% annually.
- Ohmic losses are considered as 1.5%.

Given the solar irradiance, geographical locality and PV system yield, the annual energy yield has been calculated.[6].

Table 2: Annual Energy Yield from 5 kW, 10 kW and 15 kW PV systems.

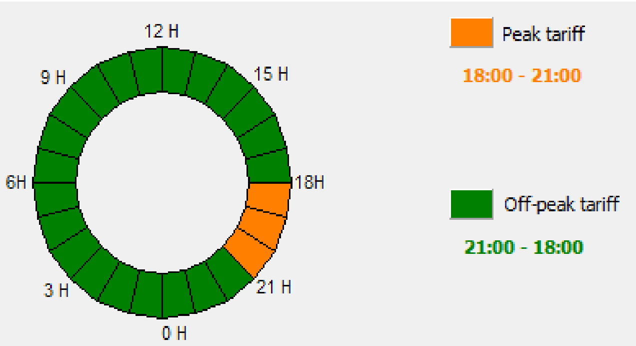
System Sizing	Total Annual Energy Yield (PV)
5 kW	6,932 kWh
10 kW	14,678 kWh
15 kW	21,700 kWh

After initializing the output of solar PV system in PVSYST for the household consumption patterns, technical assessment took into account both off-peak

[6] The mathematical relations and formulations has been demonstrated in Annexure-I.

and on-peak retail tariff.[7] The net-metering regulations in Pakistan however has pegged the rate of energy fed into grid (by prosumers) at off-peak retail tariff. **Figure 5** demonstrates the time of use structure for the net-metered systems.

Figure 5: Hours definition for On-Peak/off-Peak tariff.



So time of use in this analysis optimizes the output to the user and grid through the sun hours and geographical locality. The on-peak[8] and off-peak tariff taken are PKR 20.7 and PKR 14.7 respectively. Against the intake of energy from the grid at two different tariffs, the excess energy export to the grid is calculated at off-peak tariff.

Life-cycle costs for all 3 system sizes selected for this analysis could be seen in **Table 3**.

Table 3: Total Life-cycle costs of the systems under assessment.

System Sizing	Total anticipated project cost (CAPEX + OPEX+ Inverter replacement)
5 kW	PKR. 748,100 ($ 4,765)
10 kW	PKR. 1,166,000 ($ 7,427)
15 kW	PKR 1,646,000 ($ 10,484)

Based on the total output productivity of the solar PV systems and user's self-consumption (as in **Figure 3**), the formulations for net-metered units, total return on investment, payback period and energy generation cost are used.[9]

Table 4 and **Table 5** shoes the results of both technical and economic analysis.

Table 4: Technical Productivity of PV system and Percentage reduction in Consumer's bill.

System Sizing	Technical Analysis		
	Total Annual Energy Yield (PV)	**Energy Exported to Grid**	**Percentage Reduction of the Prosumer's Electricity Bill**
5 kW	6,932 kWh	5,060 kWh	42.70%
10 kW	14,678 kWh	11,380 kWh	42.60%
15 kW	21,700 kWh	17,690 kWh	40.60%

Table 5: Economic Analysis for residential households.

System Sizing	**Economic Analysis**		
	Payback Period	**Return on Investment**	**Energy Generation Cost**
5 kW	5.5 years	166.30%	PKR. 5.77/ kWh (3.68 cents/ kWh)
10 kW	5.0 years	250.00%	PKR. 4.206/ kWh (2.67 cents/kWh)
15 kW	4.5 years	291.80%	PKR. 3.7/ kWh (2.35 cents/kWh)

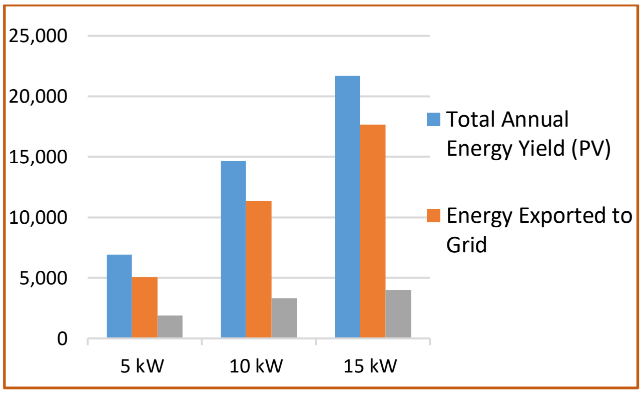
The comparative analysis for the systems under consideration is shown in the **Figure 5**.

[7] In Pakistan, consumers are charged different tariff rates based on time of use (TOU). The tariff is relatively higher in peak hours.

[8] On-peak and off-peak tariffs have been defined in PVSYST as per NEPRA's applicable tariff for 3-phase residential customers and recorded as for January, 2021.

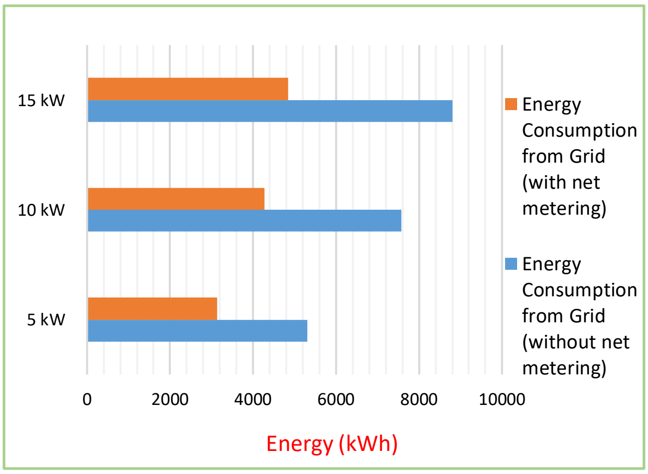
[9] The formulas and mathematical relations are mentioned in Annexure-II.

Figure 5: Comparison of Annual Total Energy production from PV system, Energy Export and Self-Consumption for 5, 10 and 15 kW prosumers.



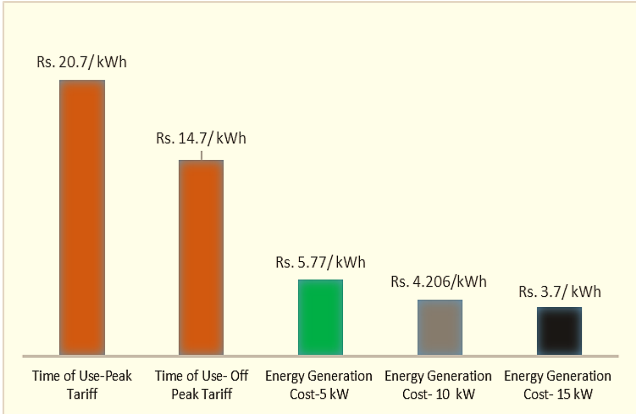
These comparisons indicate that the PV system for the residential prosumers contribute large amount of the generated energy to the grid, compared with self-consumption. The units rolled back from the PV system are generally accounted at off-peak rate while providing viable grid support operations during day time. However, to compare energy export and energy import from the grid, **Figure 6** demonstrates the comparative analysis of savings in energy consumption from the grid.

Figure 6: Difference in Annual Energy Consumption from grid with the integration of net-metered PV system.



In comparison with the applicable tariff for residential customers of the distribution grid, the energy generation cost assessed from the economic analysis yields to be significantly very low. **Figure 7** shows the comparison between the customers' tariff with the energy generation costs for the respective household prosumers.

Figure 7: Difference between the Applicable Tariffs and Energy Generation Costs.



In summary of the techno-economic assessment, it can be clearly observed that:

a. PV based net-metering offers an adequate alternate source of energy for the residential users to reduce consumption of costly energy from the grid.
b. The energy export to the grid is significantly higher than the self-consumption from the PV system which demonstrates that the PV based distributed generators can efficiently be pursued for grid electrification and offer low-cost energy integration.
c. With the very attractive payback period and return on investment, the net-metered PV system offers an ideal source of renewable energy that can be enhanced to modify with business models and third-party interventional schemes for boost-up public-private partnership for renewable energy transition.

5. Conclusion

In the past, one of the dominant barriers to PV diffusion was its high cost and unfavorable economics. The analysis carried out in this brief reveals that net-metering based solar PV system in Pakistan has not only reached grid parity—rather it has undergone a dramatic downward shift compared to retail tariff.

Broadly, this research concludes that net-metered solar PV in Pakistan today has emerged as most competitive, economically efficient, and sustainable source of energy consumption and production. Also based on the findings of this analysis, net-metered solar PV can exceed all other sources of energy. The technology also entails considerable benefits, particularly in the light of the nature of the challenges faced by Pakistan. For instance, these applications are climate safe and entail considerable environmental benefits by not producing any greenhouse gases or harmful byproducts or pollutants that accompany combustion of most thermal fuels. Secondly, these applications generate power close to the point of consumption and so are characterized by minimal line losses. Also, electricity generation on-site or close to the consumer helps reduces peak demand and hence overall congestion on the transmission network. Thirdly, as revealed by the analysis in this brief, the technology has reached grid parity, producing energy at price significantly lower than conventional energy. Fourthly, against the centralized energy system risks where one well-placed interruption may cause widespread damage to the entire grid, distributed solar contributes more to grid security in cases of such emergencies. Because of their dispersed nature, these applications are less susceptible to breakdowns or interruptions hence insulating parts of the grid from failure. Finally, all renewable applications rely on indigenous resources and are free of risks such as price volatilities, traditional fuel supply interruptions or balance of payment pressures.

Against this backdrop, society-driven renewable energy options offer policymakers an optimal opportunity to address these challenges The technology could play a key role in profoundly reshaping the energy landscape, reducing line losses, decreasing dependence on fossil fuels, improving reliability of supply, ensuring stabilized prices to end-users and most importantly improvement in the environment. But this could happen only if the drive to net-metered solar PV is fast tracked as presently it has restrictive usage, and negligible share in the energy mix.

The government of Pakistan needs to undertake a more aggressive role in prioritizing distributed generation in the overall energy transition momentum to minimize costly operation, and the current fragile state of power sector in terms of unsustainable trajectory.

Annexure-I

$$Energy\ Production\ (Wh) = A \times \eta \times H \times PR$$

Whereas;

A= Total solar panel area (m^2)

η = Efficiency of the solar plant.

H= Annual average solar irradiance[10] on tilted panels.

PR= Performance Ratio. ($PR = \frac{Achieved\ Output\ (kWh)}{Theoratical\ Output\ (kWh)}$)

Annexure-II

$$Payback\ Period = \frac{Total\ Investment\ on\ the\ system}{Annual\ Profit}$$

$$Return\ on\ Investment\ (ROI) = \frac{Net\ Profit}{Total\ Investment} \times 100$$

$$Net\ Metered\ Units = (Energy\ consumed\ from\ the\ grid) - (Energy\ exported\ to\ the\ grid)$$

$$Net\ Profit = (Total\ system\ lifecycle - Payback\ period) \times Annual\ Profit$$

$$Energy\ Generation\ Cost = \frac{Total\ return\ from\ the\ PV\ systen}{Total\ Expenditures}$$

Whereas;

$$Total\ Return = (Annual\ Energy\ Generation\ \times Lifecycle\ in\ years) \times Applicable\ Tariff$$

[10] Annual average solar irradiance is calculated as the solar irradiance (in watts) times number of hours of solar productivity.

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