Auctions in Renewable Energy and the Grid Parity Using Solar Photovoltaic Technology in Peru

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Abstract. This paper, of the network parity situation of photovoltaic solar energy with conventional electrical energy sources, such as hydroelectric and thermoelectric for Peru is analyzed. For this purpose, a review of how the electrical tariff is set for the residential end-user of conventional energy sources has been made. Furthermore, it is shown what it consists about, the cost leveled of energy for the case of photovoltaic solar energy and how this has been used for the calculation of the electric rate of this type of source. A review of the auctions of photovoltaic solar plants that are installed in: Moquegua, Tacna and Arequipa is carried out. The solar photovoltaic tariff has been obtained by auctions, between the year 2010 to 2016, these have decreased significantly until reaching network parity. The costs of both energy sources are compared.

1. Introduction
Recent years have seen rapid growth in the use of electricity obtained by renewable energy sources in their different forms of generation, such as solar and wind energy since resources such as the sun and wind are considered unlimited, unlike fossil fuels such as coal and oil that have limited duration. However, although these renewable energy sources have always existed, the costs of technology using these types of sources were so high in their infancy that the final rate of this energy was very high compared to energy from fossil sources. However, the cost of renewable electricity has fallen dramatically over the past decade due to improved technologies, economies of scale, more competitive supply chains and the growing experience of project developers. According to data from 17,000 projects collected by the International Renewable Energy Agency (IRENA) in 2019, photovoltaic solar energy (PV) cost has declined by 82% since 2010, followed by concentration solar energy (CSE) with a decrease of 47% onshore wind with 39% and offshore wind with 29% [1]. Therefore, technologies using renewable energy sources are now more competitive.

With regard to photovoltaic solar energy and CSE, the cost of electricity generated from this source recorded a decrease of 82% between 2010 and 2019. The cost improvements experienced since 2010 have been mainly due to a 90% reduction in module prices, along with lower system balance costs. All this led to a reduction in the total cost of solar PV installation of nearly 80% in the last decade [1].
With regard to renewable energy sources, Peru incorporated this type of energy into its matrix; both wind farms and solar plants are already in operation in different parts of the country. With the aim of the growth of this type of energy, the Peruvian government promulgated Legislative Decree No. 1002 "Law on the Promotion of Investment in Electricity Generation with the Use of Renewable Energy" in 2008 updated in 2010 [2], which mentions that Renewable Energy Resources (RER) in Peru opens the door to global trends in the field of renewable energies. In this area, beyond conventional power plants such as hydroelectric and thermal power plants that have been operating in the country, the promotion of unconventional renewable energies, including wind, solar, and mini-hydraulic energy is continued [3].

This document focuses on the supply of electricity from renewable energy sources, specifically in the solar photovoltaic part and auctions for this type of energy in the case of Peru. From the auctions, we analyze whether Peru achieves a network parity. Therefore, with the purpose of incorporating RERs into its energy matrix, the Peruvian government, through the document that the Ministry of Energy and Mines (MINEM) presented, an executive report of the National Energy Plan 2014 – 2025 [3], which analyses the sectoral policy measures to be implemented in order to achieve security and universal access to energy supply; on the other hand, this executive report shows the energy matrix by source type. The evolution of electricity production (GWh) in the energy market in the case of Peru [4] is shown in Figure 1. Where RERs come into operation from 2012.

![Figure 1. Evolution of the National Electricity Offer by Source until 2018.](image)

Figure 1 shows that the production of electricity from 2000 to 2018. In this last year of the graph shown, RERs generated a total of 2247.84 GWh (Solar: 745.40 and Wind: 1502.44) this represents a 4% of the total power generation [4], this is shown in figure 2. However, according to legislative decree No. 1002 shows that the objective is 5% of the participation.
Figure 2. Comparison of participation in RERs in Peru.

Figure 2 shows the comparison of RERs in their beginnings and in 2018, showing that energy from hydroelectric plants continues to have a remarkable share with 57% while solar photovoltaic energy participates by only 1%. This document focuses on the costs of photovoltaic energy for the end user and whether they reached a network parity. For this reason, the previous concepts of parity and the level cost are reviewed, the setting of the rates for the user of conventional energy sources are analyzed, the costs offered by solar photovoltaic energy in the four auctions given in Peru are checked and finally all the data is analyzed.

2. Grid parity in Peru

2.1. Grid parity

Grid parity is defined from the point of view of the end user (residential user) as the time when the retail price of network electricity (the one a consumer pays to their power company) is equated with the PV production cost [5]. That is, grid parity is the condition that occurs when a source of electricity generation, is capable of producing at a cost less than or equal to the general price of purchase of electricity directly from the electricity grid; in the case of Peru, for the most part, electricity sources are hydropower and thermoelectric plants.

Grid parity is mainly used in reference to RERs, in particular solar photovoltaic energy and wind energy, which for this document are those that will be taken into account since they are the ones that have been installed the most in Peru. Several countries have reached the parity of the PV network as the level energy cost (LCOE) of the technology in these places can be compared with local retail electricity prices competitively [6], i.e. they reach a rate less than or equal to the rate of conventional sources.

LCOE is a simple metric that provides the price of electricity per kWh (Kilowatt-hour) based on the costs distributed over the life of a power project [7]. For photovoltaic solar energy the LCOE, is a function of multiple parameters such as investment costs, cost of capital and capacity factor [8], which also includes taxes, operation and maintenance costs (O&M). In a simple way the LCOE can be expressed as:

\[ LCOE = \frac{\text{Total Cost of Useful Life}}{\text{Total Power Generation}} \ [\text{USD/MWh}] \]

Taking into account the LCOE for PV energy, energy-generating companies submit their proposals through auctions, based on these auctions the rates are set to the end user. Using the values of these rates presented in such auctions, this paper compares them with the rates of conventional sources, which is presented at the end this paper. The final rates of solar photovoltaic energy can be obtained in detail in the auctions made in Peru, for this reason, its take real data of the auctions of the RERs, since this data is available in the reports of the Ministry of Energy and Mines (MINEM), and the Supervisory Agency for Investment in Energy and Mining (OSINERGMIN). Through MINEM and OSINERMIN, it was possible to obtain the electricity tariffs of hydroelectric and thermoelectric plants.
2.2. Electricity tariffs in Peru

In Peru, the organization in charge of the regulation of electricity tariffs is OSINERGMIN, it regulates some tariffs of the electricity sector on the basis of mechanisms applied according to the specific characteristics which belongs to each of the activities of the sector [9]. The electricity tariff is composed of three price types: generation price (PG), transmission price (PT) and distribution price (PD) at the end of the sum of these prices are added some additional costs such as the other IGV detailed in Figure 3. The figure 3 shows the structure of the cost of electricity, noting that the electricity tariff paid by the final consumer is the aggregation of these prices. It should be noted that this case is exclusive for Peru, since each country has its own regulations and all electrical regulations specify a method to define the price of generation [10].

![Figure 3. Elements for setting the final rate.](image)

Most residential users of electricity in Peru belong to the tariff option called BT5B Residential which has as a characteristic the maximum consumption of 30 kWh per month without considering participations in peak or off-peak schedules, or reactive energy contributions. For all tariff specifications existing in Peru, it is possible to know the current costs [11]. Since photovoltaic power plants are located in southern Peru, between the departments of Arequipa, Moquegua and Tacna, the rates in those regions are shows in figure 4.

![Figure 4. Electricity tariff in southern Peru.](image)
The rates show in the figure 4 are the current ones up to February 2020. The rates change every month, but on average the variation is not very significant. The end user pays the cost of the consumed energy at the corresponding rate, however, the costs seen in Figure 3 are added to the rates shown in figure 4. A receipt of residential electricity consumption of the company ELECTROSUR is shown in figure 5, this company is one of the distributors of electricity in the department of Tacna. The rate shown is 0.5654 S/. /kWh which is approximately 0.16 USD/kWh.

![Receipt for residential electricity consumption](image)

**Figure 5.** Receipt for residential electricity consumption

The figure 5, corresponds to the month of May of 2019, which shows a price of 0.16 USD/kWh, which is higher than the cost of 2020 of 0.137 USD/kWh, as these rates constantly change.

2.3. **PV generation in Peru**

Photovoltaic solar (PV) generation is ready to revolutionize the electrical system in countries around the world. According to this report by the International Renewable Energy Agency (IRENA), the proportion of global electricity generated from photovoltaic solar energy will increase up to 13% by 2030 [12]. approximately. The expansion of the solar industry is mainly due to cost reduction, and the report anticipates further cost reduction up to 59% in ten years.

In Peru, in order to implement power plants with RER, several regulations were developed. The regulatory framework on RERs is constituted in the Law on the Promotion of Investment for the Generation of Electricity with the Use of Renewable Energy (Legislative Decree No. 1002), the Regulation on Electricity Generation with Renewable Energy (Supreme Decree No. 012-2011-EM) and in Regulations for the Promotion of Electricity Investment in Areas Not Connected to Network (Decree No. 012-2011-EM) and in Regulations for the Promotion of Electricity Investment in Areas Not Connected to Network (Decree No. 012-2011-EM) Supreme No. 020-2013-EM). To comply with these regulations in Peru, auctions were launched.

Auctions are the most widely used regulatory instrument in Latin America for the promotion of renewable types of energy. These are characterized by usually offering the successful tenderers a long-term energy purchase contract, lasting between 10 and 30 years. In this regard, the auction design used in the country for the award of RER generation projects is by a closed envelope system given to the best price and takes in consideration the monomie generation price, in addition to the amount of energy to be auctioned as key factors in the competition [13]. These auctions determine the photovoltaic energy prices through competitive bidding processes, where qualified project developers compete by submitting rate offers per unit of electricity [7]. The auction's bid prices largely reflect the parameters that drive LCOE calculations in USD/kWh.

Figure 6 shows the projects for PV energy projects located in the south of the country among Tacna, Moquegua and Arequipa.
Figure 6. Solar centres installed and energy produced for 2018.

Solar plants with PV energy were boosted through 4 auctions as shows in table 1, although in the third auction there was no PV power. The table shows that the first auction (four projects in total) was awarded for three departments in 2010, and they started operations at the end of 2012. The fourth auction was composed by two projects in the department of Moquegua, which included the one which showed the highest levels of power in Peru (Project Rubí, with 144.5 MW of Power) were awarded in 2016 and entered into operation in early 2018.

Table 1. RER Auctions in PV energy in Peru.

| No | Project | Department | Contract Power (MW) | Price (USD/K Wh) | Auction RER | Award Year | Began to operate |
|----|---------|------------|---------------------|------------------|-------------|------------|------------------|
| 1  | Panamerican & Solar (ILO) | Moquegua | 20 | 0.215 | 1° | 2010 | 31/12/201 |
| 2  | Majes Solar 20T | Arequipa | 20 | 0.223 | 1° | 2010 | 31/10/201 |
| 3  | Repartición Solar 20T | Arequipa | 20 | 0.223 | 1° | 2010 | 31/10/201 |
| 4  | Tacna Solar | Tacna | 20 | 0.225 | 1° | 2010 | 31/10/201 |
| 5  | Moquegua | Moquegua | 16 | 0.119 | 2° | 2011 | 31/12/201 |
| 6  | Rubí | Moquegua | 144.5 | 0.048 | 4° | 2016 | 30/01/201 |
| 7  | Intipampa | Moquegua | 40 | 0.048 | 4° | 2016 | 31/03/201 |

With regard to auction prices, its shows in table 1 that from the first auction to the fourth the rate, there has been significant reduction, which started from 0.022 USD/kWh in 2010 to 0.048 USD/kWh in 2016. It should be noted that the price drop occurred not only in Peru, but around the world. For
example in Latin America, the country of Chile presents one of the lowest rates that is 0.029 USD/kWh in 2016 [14].

3. Results

Conventional energy rates in Peru are expressed in soles/kWh. However, RER auctions are expressed in USD/kWh so to make the comparison it is necessary to express in the same currency units of USD. On the one hand, the data is grouped by auctions, and then compared. The first auction has an average cost of 0.221 USD/kWh. The second auction has an average 0.120 USD/kWh. The fourth auction has a unique price of 0.048 USD/kWh. On the other hand, conventional electricity generation in the places where solar energy (PV) plants have been installed (Arequipa, Moquegua and Tacna) has an average cost of 0.135 USD/kWh for the 2019 year. The result of comparing the costs of these two technologies is shown in figure 7.

![Figure 7. Comparison the prices between conventional and PV energy sources.](image)

In figure 7, the bars represent the energy cost of southern Peru for year in which was presented the auctions. Can see that in the first auction, the grid parity was not reached, causing a very high rate of 0.221 USD/kWh. However, in the second auction, the cost was still over the conventional energy average and for the fourth auction, the cost is lower than the conventional energy, with 0.048 USD/kWh. The cost of the fourth auction represents a 77.4% less than in the first auction which proves that the rates for this technology have reached the grid parity.

The grid parity that was reached in Peru with the rate of 0.048 USD/kWh is definitely a good improvement. However, compared to other countries in the Latin America, this is still high. For example, Chile who was mentioned previously, achieved a rate of 0.029 USD/kWh [14] in 2016. The price drop has several factors, such as location, and technology, among others. With regard to photovoltaic technology between 2010 and 2016, solar module manufacturing costs decreased by almost 74% (from 1.85 USD/W to 0.48 USD/W), while non-modular costs decreased by almost 53% (from 1.39 USD/W to 0.66 USD/W) [7].

4. Conclusions

A comparison between the costs of RER auctions and residential-level rates with conventional source was presented. The first auction energy PV in the Peru, was 0.221 USD/kWh in 2010, while the last auction was taken place in 2016 with a price of 0.048 USD/kWh. The results of the comparison show that with the last price, the grid parity was reached, as the average residential rate for the regions
analyzed (Arequipa, Moquegua and Tacna) is 0.135 USD/kWh. On the other hand, a 2019 receipt in the department of Tacna shows a fee of 0.160 USD/kWh.

The structure for setting rates for the end user at the residential level was presented. The rates are different by region. The rates shown take in consideration regions where photovoltaic solar energy (Arequipa, Moquegua and Tacna) was auctioned.

The share for 2018 of the RER is 4%. The goal is to reach a 5% participation, which is about to be reached for this goal. Future work will analyze the prospective generation costs for subsequent years.

5. References
[1] IRENA – International Renewable Energy Agency 2020, Conclusiones principales: Costos de generación de energía renovable en 2019 https://irena.org/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Costs_2019_ES.PDF?la=en&hash=A74F5A6BA01D86C175702B4F27C7086AF5D23F99
[2] Congress of the Republic of Peru 2015 Legislative Decree promoting investment for the generation of electricity with the use of renewable energies, vol. 1, no. 4. pp. 1–6
[3] MINEM 2014, Plan Nacional de Energía 2014-2025. Lima
[4] MINEM 2020, Anuario Estadístico de Electricidad 2018: Evolución en el Sector Eléctrico, Lima
[5] J. González 2012, Grid Parity Observatory: Analysis of the arrival of network parity to major global photovoltaic markets. Universidad Pontificia Comillas, Madrid
[6] Mr L. Talavera, J. De La Casa, E. Muñoz-Cérón, and G. Almonacid 2014 Grid parity and self-consumption with photovoltaic systems under the present regulatory framework in Spain: The case of the University of Jaén Campus, Renew. Sustain. Energy Rev. 33, pp. 752–771
[7] Z. Dobrotkova, K. Surana, and P. Audinet 2018 The price of solar energy: Comparing competitive auctions for utility-scale solar PV in developing countries, Energy Policy, vol. 118, no. June 2017, pp. 133–148
[8] M. Bazilian et al. 2013 Re-considering the economics of photovoltaic power, Renew. Energy, vol. 53, pp. 329–338
[9] OSIENRGMIN 2016 La industria de la electricidad en el Perú: 25 años de aportes al crecimiento económico del país. Lima
[10] Deputy Management of Tariff Regulation - OSIENRGMIN 2014 Notes for the National Energy Plan: Energy Security, OSIENRGMIN. Lima
[11] OSIENRGMIN, Pliegos Tarifarios aplicables al Cliente Final https://www.osinergmin.gob.pe/seccion/institucional/regulacion-tarifaria/pliegos-tarifarios/electricidad/pliegos-tarifarios-cliente-final
[12] D. Gielen, R. Kempener, M. Taylor, F. Boshell, and A. Seleem 2016 Letting in the light: How Solar Photovoltaics Will Revolutionise the Electricity System
[13] OSIENRGMIN 2017 La Industria de la Energía Renovable en el Perú, Ed. Osinergmin, Lima vol. 1
[14] Z. Dobrotkova, P. Audinet, and G. Sargsyan 2017 What Drives the Price of Solar Photovoltaic Electricity in Developing Countries?, World Bank Gr